REPEATABILITY OF RAMBLING AND TREMBLING AS MEASURES OF STATIC BALANCE

(1)Panjan Andrej, (2,3)Šarabon Nejc

(1)Wise Technologies, Ltd., Laboratory for Advanced Measurement Technologies, Ljubljana, Slovenia
(2)S2P, Science to Practice, Ltd., Laboratory for Motor Control and Motor Behaviour, Bled, Slovenia
(3)University of Primorska, Science and Research Centre Koper, Institute for Kinesiology Research, Koper, Slovenia

ABSTRACT

The aim of this study was to test the repeatability of rambling and trembling parameters measured during a static test of the human balance on a force plate (center of pressure). It is know from literature that the control system for equilibrium includes at least two subsystems that are assessed with rambling and trembling. Displacement of center of pressure can be decomposed of into two components, where migration of the reference point is called rambling and migration around the reference is trembling. 25 healthy subjects were included in the study. Repeatability was evaluated with the standard error of measurement, intraclass correlation coefficient and coefficient of variation. Argumentation and discussion of the gained results are provided.

Key words: static balance, motor control, repeatability, reliability

INTRODUCTION

Balance is a fundamental ability of human movement. Maintaining balance during anti-gravitational activities as well as proper body posture represent a ground-stone for the execution of other secondary movements. These are used to propel ourselves through space or manipulate with the surrounding environment (Winter, 1995). Apart from the high demands for extreme levels of balance perfection in some sports (gymnastics, alpine skiing, etc.), there is another end of this motor ability; for example risk of falling in elderly people in everyday situations. When balance is diminished, the risk of falling increases (Baczkowicz, Szczegielniak, & Proszkowiec, 2008). Falls represent one of the most serious health problems in elderly population. Poor balance has been shown to be affected by different pathologies and can even be their origin (de Noronha, Refshauge, Herbert, Kilbreath, & Hertel, 2006). On the other hand superior athletic skills require good balance as well.

Balance can be mechanically defined as the ability to sustain the center of body mass in limits of the support surface (Sarabon, Rosker, Loefler, & Kern, 2010), where support surface is defined as the convex hull of the feet. When these demands are not met anymore, body starts to fall. Human body uses different strategies to maintain balance. The two most general one are ankle and hip strategies (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998; Winter, 1995). The first strategy is usually used to compensate rotational or smaller perturbations, while the second one is used when the support surface translates, or when the perturbation to balance is bigger.

In this experiment, we focused on static balance (quite standing) of the human body that is the ability to maintain specific posture. It is usually obtained in a standing subject with devices that measure the movements of the body or its center of pressure (COP). Nowadays, the most common device used for such measurements is force platform (Błaszczyk, 2008; Raymakers, Samson, & Verhaar, 2005) which measures the COP of the whole human body.

The aim of the experiment was to evaluate the repeatability of rambling and trembling approach that was first proposed by Zatsiorsky & Duarte (2000). Repeatability is one of the basic metric characteristics of the test and therefore it is important that we use only highly repeatable parameters for the evaluation of the COP; otherwise, we may give false or nonreplicable conclusions. Rambling and trembling is one of many possible techniques used to quantify COP trajectory (Panjan & Sarabon, 2010). Basic idea is to decompose COP displacement into two components. The reference point migration is called rambling and the COP migration around the reference point is called trembling.

METHODS

Twenty-five healthy subject between 15 and 55 years of age participated in the study. Participants gave their written consent to participate in the study. All procedures conformed to the 1964 Declaration of Helsinki and were approved by the Committee for Medical Ethics at the Ministry of Health (Slovenia). Before performing tests the whole procedure was presented in details to each subject separately.

Each subject underwent a set of two tests. First test was barefoot parallel stance (PS) with active position in knees, arms on hips and focused view at specified point in front of the subject. Second test was barefoot single leg (SL) stance (dominant leg) with active position at the knee, arms on the hips and focused view at the specified point in front of the subject. Each subject performed tree repetitions of each test (six repetitions altogether) in random order to eliminate the effect of influence between the tests. All repetitions took 60 seconds with 90 seconds rest interval.

Measurements were carried out using a Kistler force plate that can provide projection of COP and forces in three directions (Fx, Fy and Fz) where Fz is vertical component and Fx and Fy are horizontal components (F_{hor}) in right handed coordinate system. Signals were acquired with a standard personal computer at sampling rate of 1000 Hz. Pre-processing of signals consisted of filtering the signals with the band-pass Butterworth filter (low cut-off frequency was 0.1 Hz, high cut-off frequency was 20Hz and order was 2). Analysis was carried out with custom made software (made in LabVIEW 2010) based on the description of rambling and trembling in Zatsiorsky and Duarte (1999, 2000). Statistical analysis were made with SPSS PASW Statistics 18 software and Spreadsheet for Calculating Reliability ("New View of Statistics: Reliability Calculations," n.d.). Mean values (MV) and standard deviations (SD) of each trial and all trials together, minimum value, maximal value, typical error (TE) and coefficient of variation (CV%) were calculated with Spreadsheet for Calculating Reliability. Single (ICCs) and average (ICCa) intraclass correlation coefficients (two-way random model and absolute agreement type) were calculated with SPSS.

Rambling and trembling decompositions start from locating the COP positions at the instants when $F_{hor} = 0$, the instant equilibrium positions (IEP). During upright standing, when the human body is at an IEP, the COP coincides with the gravity line. The rambling and trembling components of the COP trajectory were computed in the following way. The particular moments when F_{hor} changed its sign from positive (negative) to negative (positive) were selected and then the instants at which $F_{hor} = 0$ were estimated by local linear interpolation of the F_{hor} time-history data. The COP positions at these instants (the instant equilibrium points, IEP, or zero-force points) were determined. To obtain an estimate of the rambling trajectory, the IEP discrete positions were interpolated by cubic spline functions. To obtain the trembling trajectory, the deviation of the COP from the rambling trajectory was determined (relative COP position). The method is described in detail elsewhere (Zatsiorsky & Duarte, 1999, 2000).

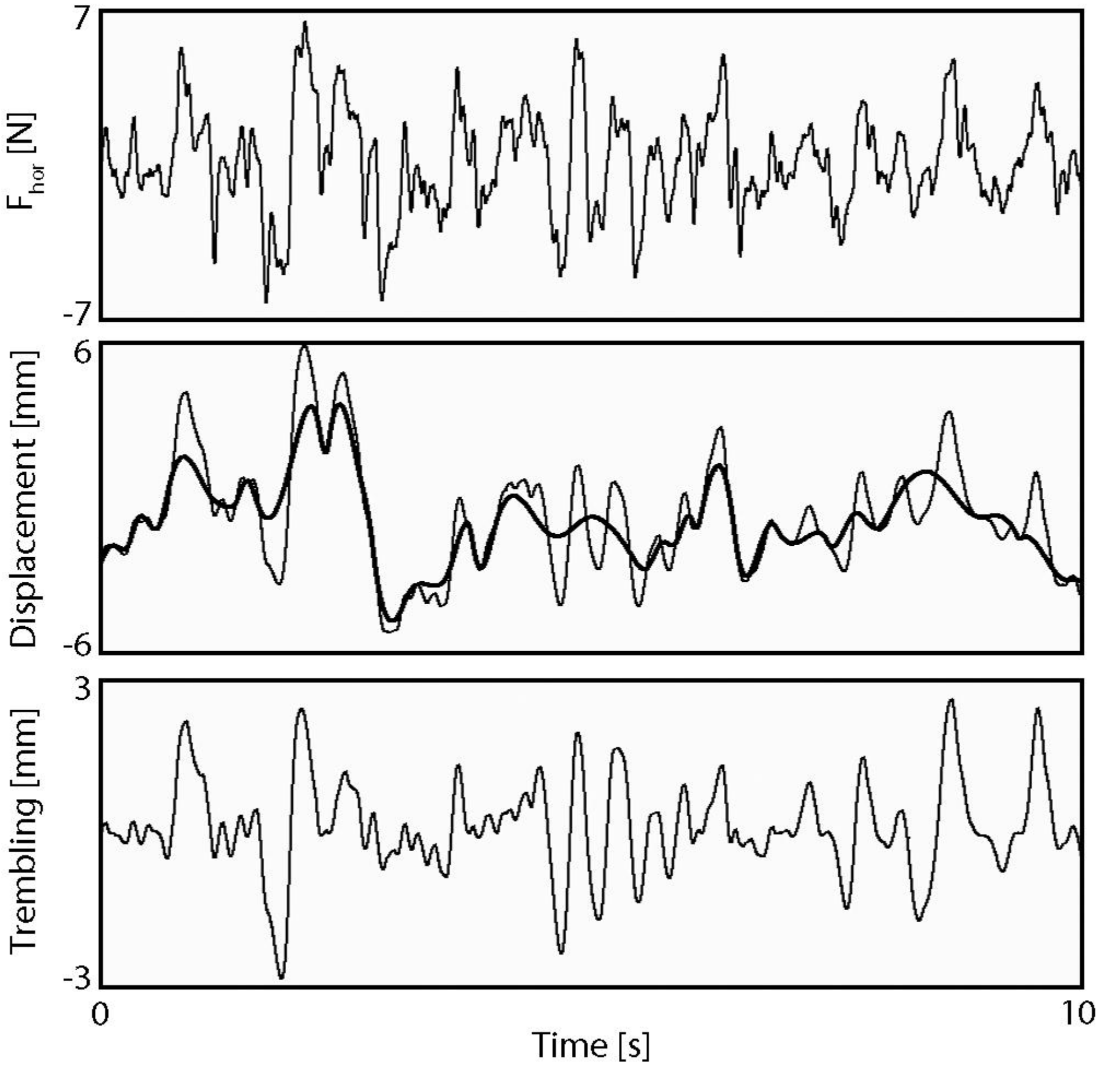

Figure 1. Example of (a) horizontal force with IEP, (b) COP displacement (thin line) and spline interpolated rambling trajectory (thick line), and (c) trembling trajectory.

Abbreviations that were used for the description of parameters in the rest of the paper are as follows: ML – medio-lateral, AP anterio-posterior, R – rambling, T – trembling, COP – center of pressure, SD – standard deviation, % - percent, MF – mean frequency, MeF – mediane frequency, PF – peak frequency, CC – cross correlation.

RESULTS

Results are presented in Teble 1 for PS and in Table 2 for SL respectively.

Parameter	Trial 1	Trial 2	Trial 3	Mean score	Range	TE	CV%	ICCs	ICCa
ML_COP_SD [mm]	0.94 ± 0.35	0.91 ± 0.37	0.98 ± 0.46	0.94 ± 0.40	0.40 - 2.24	0.22	22.87	0.66	0.85
ML_R_SD [mm]	0.92 ± 0.36	1.07 ± 1.00	0.93 ± 0.37	0.97 ± 0.65	0.39 - 5.87	0.71	72.96	0.16	0.36
ML_%_R_COP_SD [%]	98.67 ± 15.79	100.07 ± 22.42	97.01 ± 9.41	98.55 ± 16.58	71.91 - 195.69	12.14	12.32	0.00	0.00
ML_T_SD [mm]	0.32 ± 0.26	0.52 ± 1.07	0.30 ± 0.24	0.38 ± 0.64	0.06 - 5.83	0.76	200.84	0.06	0.16
ML_%_T_COP_SD [%]	34.10 ± 24.59	36.20 ± 31.04	30.21 ± 16.57	33.44 ± 24.61	8.21 - 162.66	15.05	45.01	0.00	0.00
ML_COP_MF [Hz]	0.49 ± 0.16	0.49 ± 0.14	0.48 ± 0.15	0.49 ± 0.15	0.21 - 0.88	0.11	22.23	0.38	0.65
ML_COP_MeF [Hz]	0.34 ± 0.16	0.34 ± 0.12	0.31 ± 0.12	0.33 ± 0.14	0.08 - 0.67	0.10	30.11	0.26	0.52
ML_COP_PF [Hz]	0.27 ± 0.21	0.17 ± 0.15	0.18 ± 0.12	0.21 ± 0.16	0.02 - 0.77	0.15	72.07	0.10	0.24
ML_R_MF [Hz]	0.63 ± 0.80	0.87 ± 1.30	0.45 ± 0.23	0.65 ± 0.89	0.23 - 6.15	0.93	142.60	0.16	0.36
ML_R_MeF [Hz]	0.32 ± 0.16	0.40 ± 0.32	0.26 ± 0.10	0.32 ± 0.21	0.08 - 1.75	0.23	72.44	0.03	0.09
ML_R_PF [Hz]	0.24 ± 0.21	0.15 ± 0.10	0.15 ± 0.11	0.18 ± 0.15	0.02 - 0.72	0.12	67.91	0.17	0.38
ML_T_MF [Hz]	2.03 ± 1.49	2.01 ± 1.32	2.12 ± 1.28	2.05 ± 1.37	0.29 - 6.37	1.03	50.20	0.43	0.69
ML_T_MeF [Hz]	1.04 ± 0.73	1.00 ± 0.50	1.18 ± 0.77	1.07 ± 0.68	0.12 - 3.97	0.48	44.70	0.49	0.75
ML_T_PF [Hz]	1.34 ± 1.55	1.06 ± 1.39	1.22 ± 1.35	1.21 ± 1.43	0.02 - 3.97	0.84	69.36	0.58	0.81
ML_COP_F_CC	0.51 ± 0.13	0.49 ± 0.14	0.47 ± 0.15	0.49 ± 0.14	0.11 - 0.83	0.09	18.85	0.51	0.76
ML_R_F_CC	0.45 ± 0.09	0.38 ± 0.20	0.40 ± 0.17	0.41 ± 0.16	-0.17 - 0.66	0.14	35.23	0.21	0.45
ML_T_F_CC	0.19 ± 0.32	0.24 ± 0.30	0.26 ± 0.30	0.23 ± 0.31	-0.48 - 0.74	0.23	98.46	0.53	0.77
AP_COP_SD [mm]	2.78 ± 0.64	2.72 ± 0.73	2.74 ± 1.08	2.75 ± 0.84	1.30 - 7.65	0.44	16.15	0.62	0.83
AP_R_SD [mm]	6.43 ± 20.46	4.34 ± 7.06	2.98 ± 2.00	4.59 ± 12.55	1.16 - 112.76	11.37	247.91	0.00	0.01
AP_%_R_COP_SD [%]	94.09 ± 3.44	111.83 ± 51.93	111.57 ± 72.94	105.90 ± 52.04	63.08 - 470.88	53.61	50.63	0.00	0.00
AP_T_SD [mm]	4.37 ± 20.82	2.49 ± 7.42	1.23 ± 2.40	2.70 ± 12.84	0.17 - 112.64	11.56	428.24	0.01	0.03
AP_%_T_COP_SD [%]	18.57 ± 7.17	42.69 ± 71.61	29.20 ± 37.66	30.15 ± 46.90	7.56 - 277.62	54.62	181.13	0.01	0.02
AP_COP_MF [Hz]	0.28 ± 0.08	0.27 ± 0.10	0.30 ± 0.12	0.28 ± 0.10	0.15 - 0.75	0.07	23.43	0.45	0.71
AP_COP_MeF [Hz]	0.16 ± 0.06	0.14 ± 0.07	0.15 ± 0.11	0.15 ± 0.08	0.07 - 0.63	0.06	38.93	0.35	0.62
AP_COP_PF [Hz]	0.13 ± 0.07	0.10 ± 0.06	0.09 ± 0.08	0.11 ± 0.07	0.02 - 0.35	0.05	48.66	0.38	0.65
AP_R_MF [Hz]	0.37 ± 0.77	0.98 ± 1.88	0.66 ± 1.39	0.67 ± 1.42	0.13 - 6.80	1.51	224.22	0.03	0.09
AP_R_MeF [Hz]	0.17 ± 0.20	0.31 ± 0.50	0.22 ± 0.33	0.23 ± 0.36	0.07 - 1.97	0.39	167.25	0.05	0.14
AP_R_PF [Hz]	0.12 ± 0.06	0.10 ± 0.06	0.09 ± 0.06	0.10 ± 0.06	0.02 - 0.27	0.04	40.27	0.47	0.73
AP_T_MF [Hz]	1.93 ± 1.20	2.32 ± 1.79	2.15 ± 1.43	2.13 ± 1.49	0.92 - 6.83	1.52	71.14	0.03	0.07
AP_T_MeF [Hz]	1.14 ± 0.59	1.23 ± 0.61	1.19 ± 0.63	1.19 ± 0.61	0.62 - 3.95	0.27	22.81	0.81	0.93
AP_T_PF [Hz]	1.70 ± 1.56	1.40 ± 1.37	1.61 ± 1.51	1.57 ± 1.48	0.03 - 3.97	1.09	69.60	0.44	0.70
AP_COP_F_CC	0.45 ± 0.13	0.43 ± 0.12	0.45 ± 0.14	0.44 ± 0.13	0.13 - 0.83	0.07	15.27	0.61	0.82
AP_R_F_CC	0.33 ± 0.12	0.28 ± 0.12	0.30 ± 0.12	0.30 ± 0.12	-0.04 - 0.55	0.09	30.16	0.39	0.65
AP_T_F_CC	0.68 ± 0.17	0.61 ± 0.27	0.67 ± 0.20	0.65 ± 0.22	-0.08 - 0.94	0.21	32.31	0.12	0.30

Table 1. Results of repeatability analysis for PS. For Trial 1, Trial 2, Trial 3 and Mean score fields contain mean value ± standard deviation; Range fields contains minimum – maximum values.

Parameter	Trial 1	Trial 2	Trial 3	Mean score	Range	TE	CV%	ICCs	ICCa
ML_COP_SD [mm]	3.03 ± 0.76	3.05 ± 0.76	3.06 ± 1.43	3.05 ± 1.04	1.57 - 9.78	0.58	18.89	0.66	0.85
ML_R_SD [mm]	2.61 ± 0.89	2.73 ± 1.01	2.77 ± 1.76	2.70 ± 1.28	1.10 - 8.85	1.12	41.45	0.27	0.53
ML_%_R_COP_SD [%]	85.16 ± 13.17	89.84 ± 26.38	81.71 ± 8.32	85.62 ± 17.77	62.75 - 217.48	21.46	25.06	-0.07	-0.26
ML_T_SD [mm]	1.54 ± 0.75	1.56 ± 1.09	1.59 ± 1.45	1.57 ± 1.13	0.74 - 8.71	1.03	65.90	0.14	0.34
ML_%_T_COP_SD [%]	50.25 ± 17.02	45.68 ± 12.43	44.80 ± 10.07	46.95 ± 13.54	24.30 - 109.87	10.85	23.11	0.03	0.09
ML_COP_MF [Hz]	0.68 ± 0.21	0.63 ± 0.16	0.68 ± 0.17	0.66 ± 0.18	0.32 - 1.19	0.10	14.37	0.68	0.86
ML_COP_MeF [Hz]	0.44 ± 0.21	0.37 ± 0.18	0.43 ± 0.18	0.41 ± 0.19	0.08 - 1.05	0.13	32.04	0.48	0.73
ML_COP_PF [Hz]	0.17 ± 0.15	0.14 ± 0.13	0.15 ± 0.15	0.15 ± 0.14	0.02 - 0.72	0.11	75.44	0.31	0.58
ML_R_MF [Hz]	0.74 ± 1.05	0.73 ± 1.07	0.63 ± 1.31	0.70 ± 1.15	0.20 - 7.42	1.16	165.68	-0.05	-0.20
ML_R_MeF [Hz]	0.26 ± 0.19	0.24 ± 0.24	0.28 ± 0.37	0.26 ± 0.28	0.07 - 2.17	0.24	93.76	0.13	0.30
ML_R_PF [Hz]	0.14 ± 0.12	0.11 ± 0.08	0.11 ± 0.09	0.12 ± 0.10	0.02 - 0.53	0.08	63.98	0.29	0.55
ML_T_MF [Hz]	2.01 ± 1.20	2.12 ± 1.17	1.93 ± 1.24	2.02 ± 1.21	1.08 - 7.54	1.28	63.58	-0.06	-0.23
ML_T_MeF [Hz]	1.27 ± 0.30	1.29 ± 0.28	1.36 ± 0.34	1.31 ± 0.31	0.75 - 2.23	0.25	19.11	0.33	0.59
ML_T_PF [Hz]	0.92 ± 0.39	0.88 ± 0.37	1.04 ± 0.41	0.95 ± 0.39	0.03 - 1.97	0.30	32.01	0.37	0.63
ML_COP_F_CC	0.63 ± 0.11	0.59 ± 0.12	0.61 ± 0.13	0.61 ± 0.12	0.22 - 0.80	0.06	10.51	0.70	0.88
ML_R_F_CC	0.31 ± 0.10	0.27 ± 0.13	0.30 ± 0.12	0.29 ± 0.12	-0.02 - 0.58	0.08	28.27	0.54	0.78
ML_T_F_CC	0.77 ± 0.15	0.77 ± 0.14	0.78 ± 0.16	0.77 ± 0.15	0.11 - 0.91	0.16	20.61	0.03	0.09
AP_COP_SD [mm]	4.02 ± 0.85	4.28 ± 1.36	4.20 ± 2.32	4.16 ± 1.63	2.25 - 15.42	1.08	25.92	0.50	0.75
AP_R_SD [mm]	3.49 ± 1.93	6.88 ± 15.39	3.26 ± 1.55	4.55 ± 9.00	1.68 - 83.42	10.76	236.74	0.04	0.10
AP_%_R_COP_SD [%]	79.01 ± 8.38	80.25 ± 8.36	79.01 ± 8.17	79.41 ± 8.30	54.46 - 98.92	5.65	7.12	0.00	-0.01
AP_T_SD [mm]	2.20 ± 2.16	5.64 ± 15.93	1.98 ± 1.57	3.27 ± 9.32	0.91 - 84.71	11.29	344.84	0.01	0.03
AP_%_T_COP_SD [%]	45.25 ± 8.33	44.83 ± 11.60	45.18 ± 11.01	45.09 ± 10.40	20.02 - 70.44	5.73	12.70	-0.01	-0.02
AP_COP_MF [Hz]	0.62 ± 0.17	0.60 ± 0.19	0.67 ± 0.30	0.63 ± 0.22	0.35 - 1.88	0.15	23.04	0.52	0.76
AP_COP_MeF [Hz]	0.39 ± 0.16	0.35 ± 0.19	0.41 ± 0.22	0.38 ± 0.19	0.10 - 1.05	0.12	29.93	0.61	0.83
AP_COP_PF [Hz]	0.22 ± 0.19	0.19 ± 0.16	0.16 ± 0.11	0.19 ± 0.16	0.02 - 0.68	0.14	72.91	0.17	0.39
AP_R_MF [Hz]	0.56 ± 0.97	0.71 ± 1.10	0.45 ± 0.27	0.57 ± 0.86	0.19 - 5.82	0.95	166.35	-0.03	-0.09
AP_R_MeF [Hz]	0.24 ± 0.26	0.27 ± 0.28	0.20 ± 0.08	0.24 ± 0.23	0.07 - 1.63	0.24	101.33	0.09	0.22
AP_R_PF [Hz]	0.14 ± 0.10	0.13 ± 0.07	0.12 ± 0.07	0.13 ± 0.08	0.02 - 0.55	0.06	43.87	0.42	0.68
AP_T_MF [Hz]	1.72 ± 0.95	1.91 ± 0.96	1.81 ± 0.57	1.81 ± 0.85	0.97 - 5.94	0.93	51.44	-0.04	-0.15
AP_T_MeF [Hz]	1.14 ± 0.28	1.15 ± 0.28	1.19 ± 0.25	1.16 ± 0.27	0.57 - 2.03	0.20	17.49	0.55	0.79
AP_T_PF [Hz]	0.86 ± 0.35	0.80 ± 0.28	0.94 ± 0.28	0.87 ± 0.30	0.07 - 2.07	0.27	30.91	0.17	0.38
AP_COP_F_CC	0.69 ± 0.08	0.67 ± 0.09	0.67 ± 0.08	0.67 ± 0.09	0.47 - 0.85	0.05	7.45	0.64	0.84
AP_R_F_CC	0.38 ± 0.10	0.35 ± 0.12	0.36 ± 0.06	0.36 ± 0.10	-0.09 - 0.52	0.09	26.10	0.15	0.35
AP_T_F_CC	0.81 ± 0.15	0.77 ± 0.21	0.84 ± 0.06	0.81 ± 0.15	-0.01 - 0.95	0.17	20.48	0.02	0.06

Table 2. Results of repeatability analysis for SL. For Trial 1, Trial 2, Trial 3 and Mean score fields contain mean value ± standard deviation; Range fields contains minimum – maximum values.

Only few ICC average values were above 0.80 indicating highly repeatable parameters. Some inconsistencies between ICC average values of PS and SL parameters were observed, especially among frequency parameters, while ICC average values of ML_COP_SD, AP_COP_SD, ML_COP_F_CC, AP_COP_F_CC and AP_T_MeF were the most consistent in both tests. Other parameters had either moderate or low ICC average values. ICC single values of all parameters are significantly lower than ICC average values. Coefficient of variation values are the lowest for parameters listed previously as the most consisted regarding ICC average values.

DISCUSSION

Several studies used rambling and trembling approach to quantify COP trajectory (Bottaro, Casadio, Morasso, & Sanguineti, 2005; Danna-Dos-Santos, Degani, Zatsiorsky, & Latash, 2008; de Freitas, Freitas, Duarte, Latash, & Zatsiorsky, 2009; Mochizuki, Marcos Duarte, Amadio, Zatsiorsky, & Latash, 2006), however, none of them did not provide the repeatability of the parameters derived from rambling and trembling trajectories. Therefore there was a need to evaluate the outcome parameters of this method of static balance analysis.

In this paper we considered ICC average values above 0.80 as high, between 0.50 and 0.80 moderate and below 0.50 as low repeatability. Regarding PS the highest repeatability (ICC average) was observed for AP_T_MeF, ML_COP_SD, AP_COP_SD, AP_COP_F_CC and ML_T_PF indicating that these parameters are the most suitable for the evaluation of PS. Considering SL the highest repeatability (ICC average) was observed for ML_COP_F_CC, ML_COP_MF, ML_COP_SD, AP_COP_F_CC and AP_COP_MeF indicating that these parameters are the most suitable for the evaluation of SL. The most consistent parameters in both tests were ML_COP_SD, AP_COP_SD, ML_COP_F_CC, AP_COP_F_CC and AP_T_MeF implying that these parameters could be the best choice for the evaluating of any static balance task.

Regarding ICC single and average values there was major difference in favour of ICC average values (on average 0.17 for both tests), where ICC average was calculated for three repetitions. Thus it is recommended to perform at least three repetitions of each test with adequate rest intervals. Otherwise the interpretation of results may not be adequate.

TE is the change score or difference score across repetitions for each subject, while CV% is the TE normalized with mean value of all repetitions. Values of TE and CV% should be considered in the context of mean values because they depend on it. TE and CV% vales of parameters with the highest repeatability were among the smallest which strengthens our proposal that those parameters are the most suitable for the evaluating of any static balance task.

In conclusion, the set of parameters with the highest repeatability is the most suitable choice for the evaluation of human static balance as assessed by the quiet stance tasks. It could be used for the evaluation when studying risk of falls of elderly as well as in sports or rehabilitation.

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