COMPARISON OF THE PEDAR SYSTEM WITH A FORCE PLATFORM SYSTEM FOR THE ASSESSMENT OF STATIC STABILITY

Reiner Fritsch, Hartmut Riehle, University of Konstanz, Germany

INTRODUCTION: The maintenance of upright balance represents a major factor in human postural control in everyday life, sports and rehabilitation. In the last forty years the postural stability of athletes and patients has usually been measured using force platform systems (Nigg 1977). In-shoe plantar pressure soles can provide a more versatile method for both mobile and stationary aspects of motor assessment - posturography and gait analysis. The high accuracy and repeatability of the PEDAR insole system during static uniform pressure has been shown by Cavanagh (1992), McPoil (1995) and Rash (1997). The purpose of this study is to examine the relationships of postural sway data between a KISTLER force platform and the PEDAR in-shoe plantar pressure system for use in posturography.

METHODS AND PROCEDURES: Ten male competitive gymnasts (age 18.5 ± 3.6 years, height 165 ± 8.6 cm, weight 63.0 ± 10.4 kg) were asked to maintain their balance under various conditions - each with 5 trials. Three fixed standing positions with both feet side-by-side (Romberg's test) for 20 seconds and three one-legged stances for 10 or 20 seconds were measured with a KISTLER force platform (K) and PEDAR (P) insoles, simultaneously and synchronously.
For the assessment of center of pressure (COP) data under each foot the PEDAR in-shoe plantar pressure system (Firma Novel, Munich, Germany) was used with module 'On-line to Disk Gaitline' with 50 Hz. The applied PEDAR insoles (EU-size 38/39, 40/41 and 42/43), each with 99 pressure-sensitive sensors, detected pressures as low as one Newton/cm². For triggering the beginning and end of each measurement the 'multi I/O-box' of the PEDAR system was connected with the charge amplifier of the KISTLER force platform. A special software for posturography (written by Hering-Ruffert 1997) assessed (1000 Hz) and calculated (50 Hz) the COP data of the force platform based on six different forces (Fz1-Fz4, Fx, Fy).

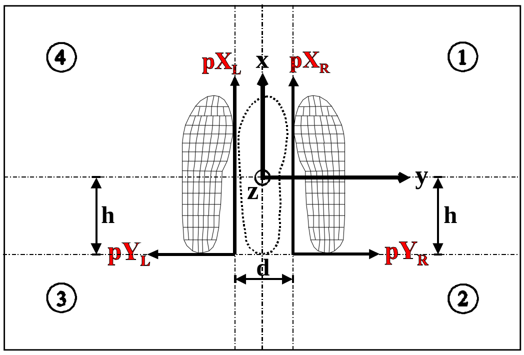

Figure 1: Fixed standing position for Romberg's test with KISTLER- and PEDAR-coordinate systems and distances (a, b; d, h) for the calculation of COP-K and COPnet; position of one-legged stances (pointed line)

1. Modified Romberg (mR), feet side-by-side (d=1cm), hands extended in front of the body, time = 20 seconds
2. Modified Romberg with feet separation of d = 10 cm (mR10) and d = 30 cm (mR30), time = 20 seconds
3. One-legged stance (OL1) with stretching position, left (OL1-L) and right foot (OL1-R) each on the x-axis (pointed line) , time = 20 seconds
4. Horizontal balance (OL2), left foot on the x-axis, time = 10 seconds
5. One-legged stance with stretching position on a wobbling mat (OL3), left foot along the x-axis (pointed line) time = 10 seconds

After data smoothing with moving averages (11 values) various center of pressure parameters (COP) were calculated for both systems: KISTLER- (K) and PEDAR coordinates (COP_K, COP_L, COP_R), PEDAR coordinates of COPnet for both feet (calculated from COP_L and COP_R, Table 1), length of COP (L-COP-K, L-COP-P), standard deviations of anterior-posterior (SD_A/P) and medial-lateral (SD_M/L) displacement. Correlations (r) and significance (t-Test) were analyzed.

Table 1: Equations for the calculation of COPnet (PEDAR) within the KISTLER coordinate system (x, y); this transformation is based on torques (M_x, M_y), distances (d, h) and PEDAR reaction forces under each foot (pF_L, pF_R)

$$COPnet = COP\_L * \frac{pF_L}{(pF_L + pF_R)} + COP\_R * \frac{pF_R}{(pF_L + pF_R)}$$

$M_y = x * (pF_L + pF_R)$	$M_x = y * (pF_L + pF_R)$
$x = x_{L'} * \frac{pF_L}{(pF_L + pF_R)} + x_{R'} * \frac{pF_R}{(pF_L + pF_R)}$	$y = y_{L'} * \frac{pF_L}{(pF_L + pF_R)} + y_{R'} * \frac{pF_R}{(pF_L + pF_R)}$
$x_{L'} = pX_L - h$ $\quad x_{R'} = pX_R - h$	$y_{L'} = -pY_L - d/2$ $\quad y_{R'} = pY_R + d/2$

RESULTS: For mR, mR10 and mR30 the anterior-posterior displacements (A/P) of COPnet are highly correlated (r_x = 0.95, p < .01) with COP_K (n = 50, 100, 500 or 1000 values). With increasing foot separation the correlation of medial-lateral displacement (M/L) for COPnet decreases from r_y(mR) = 0.88 (p < .01) to r_y(mR) = 0.53 (p < .05). (Table 2)

Table 2: Means, Standard Deviations (SD) and Numbers (n) for the Pearson Product-Moment Correlations (r_x, r_y) between the coordinates of the KISTLER force platform (COP_K) and the PEDAR insoles (COPnet calculated from COP_L and COP_R)

Correlations (r)		**A/P-displacement (COPnet)**				**M/L-displacement (COPnet)**			
** p < .01 * p < .05		**r_x** 1000 values	**r_x** 500 values	**r_x** 100 values	**r_x** 50 values	**r_y** 1000 values	**r_y** 500 values	**r_y** 100 values	**r_y** 50 values
mR	**Mean**	**0.95****	0.90**	0.73**	0.62**	**0.88****	0.84**	0.77**	0.69**
m. Romberg	**SD**	**0.04**	0.07	0.23	0.35	**0.05**	0.10	0.21	0.32
test, d=1cm	**n**	**10**	20	100	200	**10**	20	100	200
mR10	**Mean**	**0.95****	0.91**	0.86**	0.78**	**0.80****	0.76**	0.62**	0.53*
m. Romberg	**SD**	**0.03**	0.09	0.15	0.24	**0.20**	0.23	0.29	0.40
test, d=10cm	**n**	**10**	20	100	200	**10**	20	100	200
mR30	**Mean**	**0.95****	0.93**	0.86**	0.80**	**0.53***	0.43*	0.30	0.27
m. Romberg	**SD**	**0.04**	0.04	0.13	0.22	**0.16**	0.13	0.26	0.35
test, d=30cm	**n**	**10**	20	100	200	**10**	20	100	200

For all one-legged tests A/P- and M/L displacements of COP_L and COP_R (n = 50, 100, 500 or 1000 values) are highly correlated (r > 0.90, p < .01) with COP_K (Table 3, Fig. 2). All L-COP-K are 20-30% greater than L-COP-P, which is statistically significant (p < .01). For both systems SD_A/P and SD_M/L are highly correlated (r > 0.84, p < .01), but the SD_M/L of the KISTLER system are significantly higher than the SD_M/L of the PEDAR system (p<.01). (Table 4, Fig.3)

Table 3: Means, Standard Deviations (SD) and Numbers (n) for the Pearson Product-Moment Correlations (r_x, r_y) between the coordinates of the Kistler force platform (COP_K) and the left Pedar insole (COP _L) or the right Pedar insole (COP_R)

Correlations (r)		**A/P-displacement (COP)**				**M/L-displacement (COP)**			
** p < .01 * p < .05		**r_x** 1000 values	**r_x** 500 values	**r_x** 100 values	**r_x** 50 values	**r_y** 1000 values	**r_y** 500 values	**r_y** 100 values	**r_y** 50 values
OL1-L	**Mean**	**0.96****	0.96**	0.94**	0.91**	**0.94****	0.95**	0.92**	0.90**
One legged	**SD**	**0.02**	0.03	0.06	0.11	**0.03**	0.04	0.08	0.11
stance, left	**n**	**50**	100	500	1000	**50**	100	500	1000
OL1-R	**Mean**	**0.97****	0.96**	0.94**	0.93**	**0.96****	0.96**	0.96**	0.95**
One legged	**SD**	**0.02**	0.02	0.07	0.09	**0.02**	0.02	0.04	0.07
stance, right	**n**	**50**	100	500	1000	**50**	100	500	1000
OL2	**Mean**	-	**0.97****	0.95**	0.94**	-	**0.97****	0.96**	0.95**
Horizontal	**SD**	(t=10s!)	**0.02**	0.04	0.07	(t=10s!)	**0.01**	0.03	0.06
balance, left	**n**	-	**50**	250	500	-	**50**	250	500
OL3	**Mean**	-	**0.97****	0.94**	0.91**	-	**0.94****	0.93**	0.92**
Wobbling	**SD**	(t=10s!)	**0.01**	0.09	0.14	(t=10s!)	**0.05**	0.08	0.12
mat, left	**n**	-	**50**	250	500	-	**50**	250	500

Table 4: Means, Standard Deviations (SD) and Numbers (n) for the Length of COP (L-COP), Standard Deviations of anterior-posterior displacement (SD_A/P) and medial-lateral displacement (SD_M/L)

t-Test ** p < .01 * p < .05		**L-COP-Kistler** [mm]	**L-COP-Pedar** [mm]	**SD_A/P-Kistler** [mm]	**SD_A/P-Pedar** [mm]	**SD_M/L-Kistler** [mm]	**SD_M/L-Pedar** [mm]6
OL1-L	**Mean**	**721** ←**→	**532**	**6.9**	**6.7**	**6.2** ←**→	**4.0**
One legged	**SD**	130	91	1.6	1.9	1.0	0.7
stance, left, 20s	**n**	50	50	50	50	50	50
OL1-R	**Mean**	**786** ←**→	**651**	**6.7**	**6.7**	**6.4** ←**→	**4.8**
One legged	**SD**	133	100	1.2	1.5	1.4	1.4
stance, right, 20s	**n**	50	50	50	50	50	50
OL2	**Mean**	**552** ←**→	**411**	**7.7**	**7.8**	**7.5** ←**→	**4.8**
Horizontal	**SD**	119	90	2.1	2.2	1.3	0.9
balance, left, 10s!	**n**	50	50	50	50	50	50
OL3	**Mean**	**551** ←**→	**307**	**7.7** ←*→	**6.9**	**7.7** ←**→	**3.0**
Wobbling	**SD**	147	72	1.7	1.8	1.8	0.9
mat, left, 10s!	**n**	50	50	50	50	50	50

DISCUSSION: For the two-legged tests (mR, mR10 and mR30) the anterior-posterior displacements (A/P) of COPnet are highly correlated with COP_K. With increasing foot separation the correlation of medial-lateral displacement (M/L) for COPnet decreases. Thielen (1993), who did a similar study with various two-legged stances using the KISTLER force platform system and F-SCAN insoles, obtained approximately the same results. Winter (1995) explains this tendency with a hip load/unloading mechanism, whereby M/L changes are almost completely out of phase.

For all one-legged tests A/P-, M/L, SD_A/P- and SD_M/L parameters between the PEDAR- and KISTLER system are highly correlated. All COP length data calculated from PEDAR data (L-COP-P) are 20-30% smaller than L-COP-Kistler, which is statistically significant (Fig. 2). Because of the lower medial-lateral displacement values (SD_M/L) of the PEDAR insoles, L-COP-P values are significantly smaller. The lower values of the PEDAR data in M/L (Fig. 3) may possibly be explained by the subjects' feet, which are slightly wider than the insoles. Furthermore, ankle corrections of the examined subjects in one-legged stances can effect shearing force along the lateral edge of the foot; this forces on the lateral edge of the foot can only be measured in part from the PEDAR insoles, while the KISTLER force platform can assess all reaction forces completely.

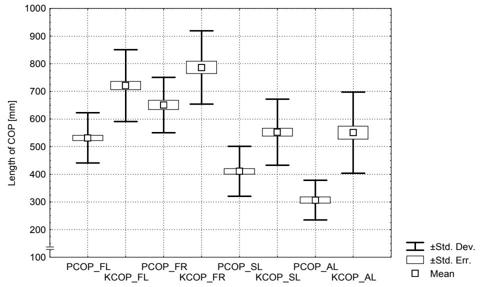

Figure 2: Length of Center of Pressure (in mm), FL-foot left (20s), FR-foot right (20s), SL-horizontal balance (10s), AL- wobbling mat (10s)

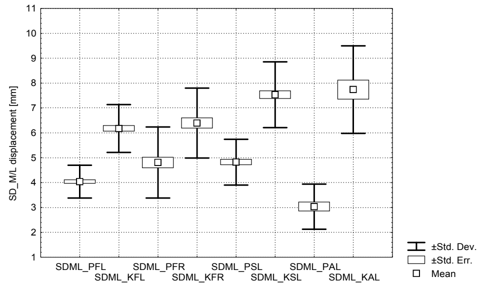

Figure 3: Standard deviation of medial-lateral displacement (SD_M/L), P-Pedar and K-Kistler

CONCLUSION: In this study very high correlations between the PEDAR- and KISTLER systems were found for various center of pressure parameters. The medial-lateral displacement values of the PEDAR insoles for all one-legged tests were lower in comparison with those of the KISTLER force platform system. Nevertheless, the PEDAR in-shoe plantar pressure system, which can be used under a greater variety of conditions, can be recommended for posturographic assessment in one- and two-legged tests.

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