Pedobarographic Features of Gait Measured by FDM1.5 PMD

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Keywords: Pedobarography, Gait, PMD, Pressure Acquisition Protocol, Data Processing, Biomechanics.

Abstract: *Backgrounds:* Main objective was to evaluate methods for assessment of pedobarographic features of gait using FDM1.5 pressure measuring device (PMD) - within complete gait analysis, with regard to device, protocol&data analysis, specifically to basic morphology and certain distinctive characteristics. *Methods:* Protocol was standardized for descriptive&inferential statistical methods (63 quantitative variables). Participants characteristics (n=22; 13 male&9 female): age 14-35 y.o., average 172,56cm body height, average 73.11kg body mass (19.47 BMI), with minimum of 5 years of regular sport&recreational activities. *Results:* Protocol output was consistent for repeated measurement of an individual. Tested differences between genders, before&after 'partialization' of results (excluded influence of longitudinal dimensionality), in both cases reveal significance in: *Stride width* (t_GSW=4.15), *Step time_L* (t_TSTL=2.88), *Step time_R* (t_TSTR=3.59), *bilateral asymmetry in Step time* (t_TST_D=3.32), *Cadence* (t_TC=-3.44) on $p<0.01$ level, and *Ant/Post position* (t_BAP=2.33), *bilateral asymmetry in Time to change heel to forefoot*(t_LTP_D=2.26), *Time maximum force Midfoot_D % of stance time* (t_TMAXM=2.33), and *bilateral asymmetry in Contact time Heel* (t_CH_D=2.33), on $p<0.05$ level. Differences in barefoot/footwear gait were specially expressed in variable *MAXPH* (t= -8.84, $p<0.05$). *Conclusions:* Statistical tools, such as partializations of the results by specific characteristic which tend to increase heterogeneity, may standardize&improve the power of the protocol and method.

1 INTRODUCTION

During ordinary activities, trainings, or competitions, high intensity foot-ground contacts affect adaptation depending on movement structure, type of surface, and generally, footwear. Health effects of barefoot gait, incidence of injuries and functional pathologies, footwear characteristics etc., are covered trough meta-analysis and reviews (e.g. Giacomozzi, 2011), primarily in order to standardize plantar pressure measurement protocols (Giacomozzi, 2010, Giacomozzi et al, 2012)

Complementarities of normal functions of ankle joint is conditioned by predisposed and phenotype factors. Articulatio Talocruraris as angle joint covers dorsal and plantar flexion (tibia, fibula, and talus). Art. subtalaris covers inversion and eversion (talus, calcaneus, cuboideum). Distal interfalangeal joints as angle joints cover flexion and extension (phalanges).

In order to reliably associate local pressure data with foot function and structure, anatomy-based masking of footprints is recommended (Giacomozzi et al., 2012). Previous to iFAB-PG convergences (in Giacomozzi, 2010), simple optic systems, e.g. Sheffield system (Franks, 1997), were used. Pressure distribution can be seen as the effectiveness of the musculoskeletal system in absorbing the ground reaction forces via the foot and its joints. Excessive foot pressure may develop into calluses, which become sites of peak pressure and pain (Caravaggi et al 2014). Therefore, in assessment of data about feet structure and function, new kinetic and kinematic pressure measurement devices (PMDs) are used (insoles, platforms, trackways, mats, etc.). After leaving optical systems (Sheffield), new approach was e.g. in Giacomozzi (2012) usage of the Oxford kinematic foot model for medio-lateral regionalisation of the foot – clinically relevant for clubfoot and flatfoot – and e.g. the Rizzoli model for longitudinal regionalisation, to clearly distinguish metatarsal from toe or midfoot loading.

Besides classical kinetic approach for measurement of vertical (Fz), antero-posterior (Fy) and medio-lateral (Fx) forces (ELITE system, Medved and Kasović, 2007), new templates for plantar pressure measurements were offered by different producers (e.g. in Giacomozzi, 2010). Template for Segmented Foot Regions and Length Measurements (FootMat software, Tekscan) where

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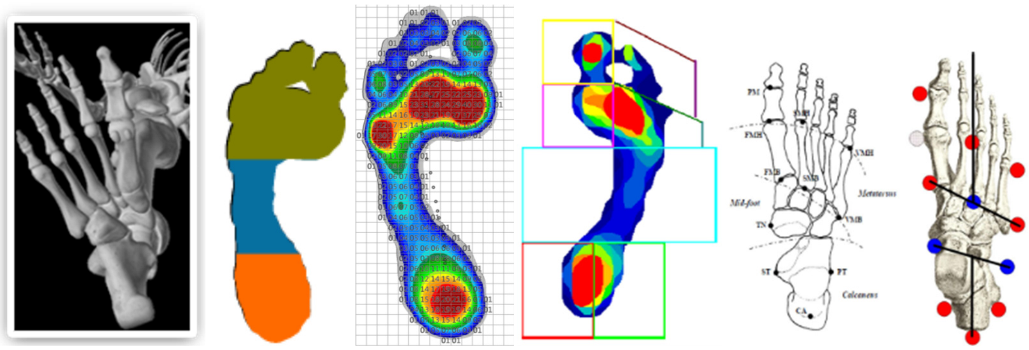

Figure 1: Examples of kinematic&kinetic models for foot analysis (Zebris: ref 13., Tekscan: Cousins et al, 2012.; Rizzoli: Leardini et al, 2007.; Oxford: Stebings et al, 2006.).

"reliable plantar pressure data that can be collected in children, aged 7 to 11 years in all regions of the foot except the lesser toes which consistently reported poor-to-moderate levels of reliability and increased variability." (Cousins et al, 2002), Novel, Zebris and other, offered their foot model (Figure 1.).

Plantar pressure measurement devices (PMDs) are now widespread mostly (Giacomozzi et al., 2012): *in the biomechanical research*, in the clinical context, as a key instrument for the prescription, design and construction of plantar orthoses. Biomechanical measurements and analyses in general, encompass spatial kinematic variables, ground reaction force, and multi-channel surface electromyography (sEMG) (Medved and Kasović, 2007).

Main objective in this paper is to join, to support, and to be in line, with mission of three main sections within i-FAB-PG - 1)Technical Assessments, 2) Data Analysis and 3) Applications, e.i. evaluation of methods for assessment of pedobarographic features of gait using FDM 1.5 PMD (Zebris Medical, Gmbh).

Trough initial insight of possibilities that FDM 1.5 platform offers, it is a goal: 1) to test preconditions for standardization of measuring protocol for complete gait analysis within Biomechanics Laboratory, Institute of Kinesiology, Faculty of Kinesiology (analysis of metric characteristics of tests, trough basic pedobarographic indicators of forces, pressures, time-spatial, and derived indicators, bilateral asymmetries), 2) to test relations of pedobarographic characteristics with basic morphology (later with kinetic and isokinetic), and 3) to analyse differences with regard to distinctive characteristics (e.g. gender, body height, bilateral asymmetries, barefoot/footwear, ect.), in order to capacitate laboratory for more demanding analysis regarding different kinesiological activities.

2 METHODS

Measurement protocol: from initial standing position (barefoot), subject walks over the trackway 9,5 m long (with centrally positioned 158 cm long and 60,5 cm wide platform - FDM1.5, ZEBRIS medical, Gmbh; sensor area 149,0x54.2 cm – L x W, sampling rate 100 Hz, optional 200 Hz/300 Hz), to the end of the trackway, turns around and goes back (6 times). During the gait, subject should be instructed to develop and reach velocity normal for aiming him/herself towards ordinary activity/duty when there are no disturbing gait aspects (late for meeting, uncomfortable footwear, company etc.). Measurements on platform are supported by 11264 capacitive sensors with density of 1.4 sensors/cm2, with measuring range 1-120 N (accuracy ±5% FS).

Reports (accessible by Zebris Medical FDM software for qualitative and quantitative analysis; for reliability Zebris refers to Giacomozzi C, 2010) offer 63 quantitative variables and graphics within groups (table 1): pressure plots, gait parameters (geometry, phases, timing) COP analysis, force&pressure parameters&curves, three foot zone analysis (Zebris model). Protocol was standardized for descriptive and inferential statistical methods. Normality of distributions of results was tested with K-S test, reliability with Cronbach alpha: 0.99 (Standardized alpha: 0.99), homogeneity with Average inter-item corr.: .99. Participants characteristics (n=22; 13 male, 9 female): age 14-35 y.o., average 172,56 cm body height, average 73.11 kg body mass (and average 19.47 BMI), with minimum of 5 years of regular sport and recreational activities.

Table 1: Pedobarographic variables (Zebris protocol).

code	description, unit, (L/D)	code	description, unit, (L/D foot)	code	description, unit, (L/D foot)
GFRL	Foot rotation, degree L	BLL	Length of gait line, mm L	MHL	Maximum force H, N L
GFRR	Foot rotation, degree D	BLR	Length of gait line, mm D	MHR	Maximum force Hl, N D
GSLL	Step length, cm L	BSL	Single support line, mm L	MAXPFL	Max pressure FF, N/cm2 L
GSLR	Step length, cm D	BSR	Single support line, mm D	MAXPFR	Max pressure FF, N/cm2 D
GSL	Stride length, cm	BAP	Ant/Post position, mm	MAXPML	Max pressure MF, N/cm2 L
GSW	Stride width, cm	BLS	Lateral symmetry, mm	MAXPMR	Max pressure MF, N/cm2 D
PSTPL	Stance phase, % L	FMF1L	Maximum force1, N L	MAXPHL	Max pressure H, N/cm2 L
PSTPR	Stance phase, % D	FMF1R	Maximum force1, N D	MAXPHR	Max pressure H, N/cm2 D
PSTLRL	Load response, % L	FTMF1L	Time maximal force1, % L	TMAXFL	Time max force FF, %L*
PSTLRR	Load response, % D	FTMF1R	Time maximal force1, % D	TMAXFR	Time max force FF , % D *
PSTMSL	Mid stance, % L	FMF2L	Maximum force2, N L	TMAXML	Time max force MF, %L*
PSTMSR	Mid stance, % D	FMF2R	Maximum force2, N D	TMAXMR	Time max force MF, % D *
PSTPSL	Pre-Swing, % L	FTMF2L	Time maximal force2, % L	TMAXHL	Time max force H, %L*
PSTPSR	Pre-Swing, % D	FTMF2R	Time maximal force2, % D	TMAXHR	Time max force H, % D *
PSWPL	Swing phase, % L	LTL	Time to change heel to FF, sec L	CFL	Contact time FF, %L*
PSWPR	Swing phase, % D	LTR	Time to change heel to FF, sec D	CFR	Contact time FF, % D *
PDSTP	Double stance phase, %	LTPL	Time to change heel to FF, % L	CML	Contact time MF, %L*
TSTL	Step time, sec L	LTPR	Time to change heel to FF, % D	CMR	Contact time MF% D *
TSTR	Step time, sec D	MFL	Maximum force FF, N L	CHL	Contact time H, %L*
TST	Stride time, sec	MFR	Maximum force FF, N D	CHR	Contact time H, % D *
TC	Cadence, steps/min	MML	Maximum force MF, N L	*TVIS*	*Body height*
TV	Velocity, km/h	MMR	Maximum force MF, N D	*ASIS*	*Leg height*

(*% of stance time; FF-Forefoot, MF-Midfoot, H-Heel)

Table 2: Pedobarographic parameters (n=22;'_D' is measure of bilateral asymmetry (L – R =_D)).

code	X±SD	code	X±SD	code	X±SD	code	X±SD
TVIS	172.56±15.97	PSWPL	38.75±1.88	FMF2L	705.23±213.29	MAXPML	10.65±5.58
L_ASIS	97.81±9.56	PSWPR	37.62±2.15	FMF2R	711.08±199.45	MAXPMR	12.42±6.00
D_ASIS	98.87±9.74	PSWPR_D	1.13±1.87	FMF2_D	-5.85±30.73	MAXPM_D	-1.77±4.21
ASIS_D	-1.06±2.40	PDSTP	23.65±3.39	FTMF2L	45.73±1.80	MAXPHL	39.41±11.59
GFRL	8.15±4.09	TSTL	0.55±0.05	FTMF2R	46.45±1.74	MAXPHR	40.13±11.51
GFRR	9.94±4.45	TSTR	0.54±0.05	FTMTF2_D	-0.73±2.45	MAXPH_D	-0.72±5.17
GFR_D	-1.79±4.84	TST_D	0.01±0.02	LTL	0.25±0.06	TMAXFL	75.13±2.00
GSLL	67.86±9.74	TST	1.09±0.09	LTR	0.24±0.06	TMAXFR	75.32±1.67
GSLR	69.82±5.72	TC	111.41±9.40	LT_D	0.01±0.05	TMAXF_D	-0.19±1.30
GSL_D	-1.95±10.11	TV	4.56±0.54	LTPL	36.36±6.13	TMAXML	42.22±8.74
GSL	137.73±12.13	BLL	217.33±32.63	LTPR	34.25±6.78	TMAXMR	39.71±8.72
GSW	11.50±3.61	BLR	223.74±22.34	LTP_D	2.11±4.39	TMAXM_D	2.50±6.51
PSTPL	61.25±1.88	BL_D	-6.41±19.01	MFL	694.84±196.64	TMAXHL	18.35±3.00
PSTPR	62.38±2.15	BSL	131.04±14.45	MFR	700.46±193.24	TMAXHR	17.08±3.23
PSTP_D	-1.13±1.87	BSR	131.29±17.70	MF_D	-5.62±21.33	TMAXH_D	1.27±2.70
PSTLRL	12.05±1.69	BS_D	-0.25±11.74	MML	122.55±69.23	CFL	89.78±2.77
PSTLRR	11.48±1.89	BAP	137.99±15.71	MMR	142.56±74.94	CFR	89.66±3.60
PSTLR_D	0.57±1.46	BLS	-1.47±2.96	MM_D	-20.01±29.40	CF_D	0.12±1.58
PSTMSL	37.63±1.82	FMF1L	679.59±187.11	MHL	490.35±119.63	CML	66.95±6.87
PSTMSR	38.89±1.85	FMF1R	684.57±186.33	MHR	476.80±108.42	CMR	68.39±6.28
PSTMS_D	-1.25±1.71	FMF1_D	-4.99±31.78	MH_D	13.55±34.54	CM_D	-1.44±5.36
PSTPSL	11.49±1.90	FTMF1L	19.00±23.98	MAXPFL	42.14±10.21	CHL	53.52±8.60
PSTPSR	12.15±1.87	FTMF1R	14.23±1.57	MAXPFR	42.05±11.52	CHR	50.84±9.29
PSTPS_D	-0.66±1.73	FTMF1_D	4.77±23.78	MAXPF_D	0.09±5.27	CH_D	2.69±5.63

Collected data were processed within Reliability/Item analysis, K-S normality tests, descriptive analysis, correlation analysis, t-test, in Statistica for W/5.0.

3 RESULTS

Pedobarographic features of normal gait are presented trough results in 63 standard, and 29 derived variables in Table 2. Gender based heterogeneity of subjects is presented in Table 3., and differences based on barefoot/footwear gait (as additional source of heterogeneity) in Table 4., followed by Figure 2. Results in Table 5 present gender based differences in certain pedobarographic features before and after using statistical tools for excluding common variance.

Table 3: Longitudinal dimensionality by gender (X±SD; M=13, F=9); t-test differences.

	x_M	x_F	t-value	p
TVIS	178.59±14.41	163.84±14.60	2.35	0.03
L_ASIS	101.35±8.45	92.70±9.12	2.28	0.03
D_ASIS	102.55±8.37	93.56±9.50	2.34	0.03

Table 4: T-test for barefoot/footwear differences.

	Mean	SD	t	p
MAXPH_barefoot	-1.8	4.37	-8.84	0.01
MAXPH _shoes	0.9	4.16		

4 DISCUSSION & CONCLUSIONS

Different approaches to assess pedobarographic features of gait (e.g. (Lorkowski and Zarzycki, 2006; Skopljak et al., 2014; Pomarino and Pomarino, 2014; Maurer et al., 2014, ect.), bring conclusions based on different PMDs and protocols. Consistency and repeatability were provided.

Pedobarographic parameters, acquired by measurement protocol on tested PMD, have shown consistent output for repeated measurement of an individual. However, within small data base and heterogeneous sample of participants, conclusions and generalizations are limited. It is the case in this paper, too.

Statistical tools, however, may improve power of the method. By ‘partializations’ of the results by specific characteristic which tend to increase heterogeneity (age, sex, longitudinal dimensionality, bilateral asymmetries, time-spatial parameters, etc.)

Table 5: Pedobarographic features; analysis of differences by gender (t-test), correlations between anthropometric variables (M+F), and variables differentiating two groups by gender criterion (r), and analysis of differences by gender after partializations on longitudinal dimensionality (t-test (p)).

	X ±SD (M=13, F=9)		r			t-test		t -test(p)	
code	X ±SD _M	X ±SD _F	TVIS	LASIS	DASIS	t	p	t	p
GSW	13.85±2.67	8.11±1.27	0.53	0.56	0.51	5.96	0.00	4.15	0.00
TSTL	0.57±0.03	0.51±0.03	0.53	0.49	0.51	4.44	0.00	2.88	0.01
TSTR	0.57±0.03	0.50±0.03	0.54	0.50	0.49	5.39	0.00	3.59	0.00
TST_D	1.14±0.06	1.00±0.06	0.55	0.52	0.52	5.07	0.00	3.32	0.00
TC	105.62±5.61	119.78±7.19	-0.58	-0.54	-0.54	-5.19	0.00	-3.44	0.00
BLL	232.22±26.58	195.83±29.24	0.84	0.80	0.81	3.03	0.01	1.47	0.16
BLR	233.78±21.95	209.23±13.67	0.91	0.89	0.84	2.97	0.01	1.84	0.08
BAP	145.65±14.83	126.91±9.19	0.88	0.83	0.80	3.36	0.00	2.33	0.03
BLS	-2.49±2.92	0.01±2.46	-0.16	-0.18	-0.13	-2.10	0.05	-1.81	0.09
FMF1L	749.17±168.57	579.08±173.32	0.90	0.87	0.82	2.30	0.03	0.60	0.56
FMF1R	759.06±169.64	576.98±161.03	0.92	0.90	0.86	2.53	0.02	0.94	0.36
FMF2L	787.57±187.20	586.30±199.81	0.89	0.84	0.85	2.41	0.03	0.62	0.54
FMF2R	787.45±182.08	600.76±177.53	0.91	0.88	0.87	2.39	0.03	0.56	0.58
LTP_D	3.68±3.84	-0.16±4.32	0.01	-0.02	-0.03	2.19	0.04	2.26	0.04
MFL	768.88±181.97	587.88±173.34	0.91	0.86	0.86	2.34	0.03	0.50	0.62
MFR	773.98±175.11	594.26±174.79	0.92	0.89	0.87	2.37	0.03	0.51	0.62
MAXPMR	14.54±6.96	9.36±1.97	0.35	0.41	0.34	2.16	0.04	1.48	0.16
TMAXM	5.41±6.62	-1.69±3.50	0.20	0.20	0.22	2.93	0.01	2.33	0.03
CF	-0.50±0.87	1.02±1.98	-0.53	-0.44	-0.44	-2.47	0.02	-1.53	0.14
CML	69.68±4.82	62.99±7.70	0.60	0.64	0.61	2.52	0.02	1.26	0.22
CH	4.76±5.92	-0.31±3.68	0.00	-0.02	-0.03	2.28	0.03	2.33	0.03

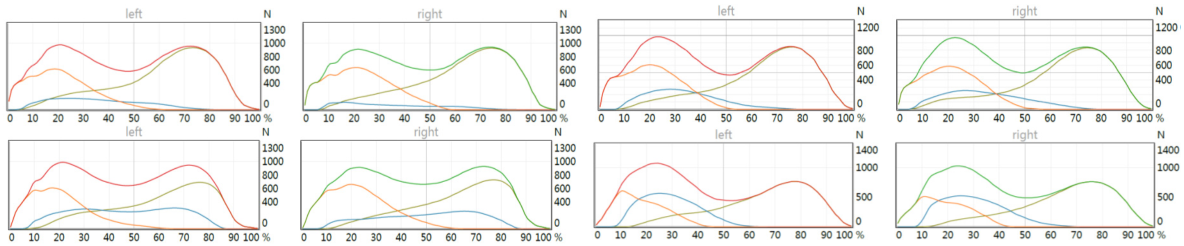

Figure 2: Barefoot gait (left graphs)/footware gait (right graphs) (Zebris); axes – x for % of measured time, y for Force (N), and 4 lines (developing from left to right – total, heel, midfoot, forefoot).

it is possible to improve power of arguments. Partializations imply extracting the common variance, and comparison between rests of true variances (explained in Milas, 2009). It goes in line with 3rd fundamental step that have to be followed towards *standardisation* in the use of PMDs (Giacomozzi et al, 2012), i.e. *definition and standardisation of data processing and reporting* (1st is definition and standardisation of tools and protocols for the technical assessment of PMD hardware performance, and 2nd is definition and standardisation of pressure acquisition protocols)

Pedobarographic features are expectedly different in male and female population due to well analysed differences in valgus knee inclinations. Tested differences between genders (table 5.), before and after partialization of results (by excluding influence of longitudinal dimensionality of subjects), in both cases reveal significance in variables: Stride width (t_GSW=4.15), Step time L (t_TSTL=2.88), Step time R (t_TSTR=3.59), bilateral asymmetry in Step time (t_TST_D=3.32), Cadence (t_TC=-3.44) on $P<0.01$ level, and Ant/Post position (t_BAP=2.33), bilateral asymmetry in Time to change heel to forefoot, % L (t_LTP_D=2.26), Time maximum force Midfoot D % of stance time (t_TMAXM=2.33), and bilateral asymmetry in Contact time Heel (t_CH_D=2.33), on $p<0.05$ level.

Differences in barefoot/footwear gait (table 4.) were specially expressed in variable MAXPH (t= -8.83782, $p<0.05$). It can be (limited) assumption, that wearing shoes influences neuromuscular and motor control(learning) decision mechanisms in a way that individual 'delegates' amortisation mechanisms in first contact (heel strike/load response) to the shoe and elastic structures of its composite materials (figure 2.). Initial greater force (during contact with shoe) spreads, and transposes impact on upper skin. Normal feet with „smaller joint mobility are associated with larger pressure at the rear- and forefoot. A trend for decreased pressure at the midfoot was also detected in feet with a stiffer medial longitudinal arch. A more flexible foot may allow better distribution of pressure at the plantar foot surface during gait thus limiting the contribution to plantar tissue damage especially in at-risk groups such as the diabetic feet." (Caravaggi et al, 2014).

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