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Comparison of Developed Statokinesigram and Marker Data Signals by Model Approach

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***Abstract*—**Background: Based on statokinezigram, the human balance control is often studied. Approach to human postural reaction analysis is based on a combination of stabilometry output signal with retroreflective marker data signal processing, analysis, and understanding, in this study. The study shows another original application of Method of Developed Statokinesigram Trajectory (MDST), too. Methods: In this study, the participants maintained quiet bipedal standing for 10 s on stabilometry platform. Consequently, bilateral vibration stimuli to Achilles tendons in 20 s interval was applied. Vibration stimuli caused that human postural system took the new pseudo-steady state. Vibration frequencies were 20, 60 and 80 Hz. Participant's body segments - head, shoulders, hips, knees, ankles and little fingers were marked by 12 retroreflective markers. Markers positions were scanned by six cameras system BTS SMART DX. Registration of their postural reaction lasted 60 s. Sampling frequency was 100 Hz. For measured data processing were used Method of Developed Statokinesigram Trajectory. Regression analysis of developed statokinesigram trajectory (DST) data and retroreflective marker developed trajectory (DMT) data were used to find out which marker trajectories most correlate with stabilometry platform output signals. Scaling coefficients (λ) between DST and DMT by linear regression analysis were evaluated, too. Results: Scaling coefficients for marker trajectories were identified for all body segments. Head markers trajectories reached maximal value and ankle markers trajectories had a minimal value of scaling coefficient. Hips, knees and ankles markers were approximately symmetrical in the meaning of scaling coefficient. Notable differences of scaling coefficient were detected in head and shoulders markers trajectories which were not symmetrical. The model of postural system behavior was identified by MDST. Conclusion: Value of scaling factor identifies which body segment is predisposed to postural instability. Hypothetically, if statokinesigram represents overall human postural system response to vibration stimuli, then markers data represented particular postural responses. It can be assumed that cumulative sum of particular marker postural responses is equal to statokinesigram.

***Keywords*—**Center of pressure (CoP), a method of developed statokinesigram trajectory (MDST), a model of postural system behavior, retroreflective marker data.

I. INTRODUCTION

HUMAN balance control is crucial ability to perform complex movement activities. Maintaining balance and spatial orientation of the human body is the main task of the musculoskeletal postural system [1]. This ability is important for preventing falls and avoiding consequential injuries [2]. Central nervous system control adjustment of the postural system in biological feedback in a situation of quiet stance posture or in motion. Proprioceptive, vestibular and visual sensory information is important for postural system control. Processing of sensory information could be influenced by various musculoskeletal disorders, neurological diseases or age [3]. In balance control research are for studying human postural reactions used stabilometry platforms, camera systems.

There is assumed essential feature of the postural system in healthy people without musculoskeletal disorders in the pseudo-steady state, according to this assumption velocity of postural sway is approximately constant in a steady state or have only slight changes.

In the condition of vibration stimuli, the postural system of human body takes the new pseudo-steady state. Vibration evokes lean of the human body in the direction of effecting actuating [4]. Velocity changes of postural sway are very sharp in compare to pseudo-steady state.

The easiest way to get appropriate postural system reaction is vibration stimuli of lower legs muscles or tendons, which causes a change of proprioceptive sensory information [5]-[7].

Modeling of postural system reaction is helpful for evaluating and accurate quantifying of postural system balance control and for revealing reasons of postural instability.

Model identification of postural reactions to Achilles tendon vibration stimuli was analyzed in a pilot study [8], which dealt mainly with statokinesigram data analysis by the method of developed statokinesigram trajectory.

Consequently, our paper is methodological orientated and continues on pilot study [8]. Comparison of postural responses measured by the stabilometry platform and by the retroreflective markers kinematic data is the basis for this study. Main goals were to find out which markers best correlate with the stabilometry platform output signal and to confirm the model of steady states constant velocities from a pilot study [8] on retroreflective marker data signal.

II. METHODS

A. Participants

Three test subjects participated as volunteers in this study. Participants were around 25(±2) years with no self-reported disorders related to the ability to maintain a balanced posture. Tested subjects have body mass index between 18.5 and 30 kg/m^2. Participants sign informed consent about recording their postural responses and processing of recorded signals.

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B. Procedures

Postural reactions of participants were registered by custom made stabilometry force platform and by three-dimensional six-cameras scanning system BTS SMART DX.

Participant's significant body segments (head, shoulders, hips, knees, ankles and feet little fingers) were marked by 12 retroreflective markers for the purpose of recording body motion kinematics in quiet stance. Little finger markers were excluded from data processing in this study, due to the noninformative character in the case of quiet stance posture.

Participants were asked to maintain a bipedal quiet upright stance posture on a firm support surface in a situation of open and closed eyes, respectively. They were vibratory stimulated bilaterally on Achilles' tendons during postural reaction registration. For stimulation of participant's postural system was used vibration stimulator with adjustable frequency intensity. Postural responses were registered in a situation with open and closed eyes and for both without vibration stimuli and with vibration stimuli set on 20, 60 and 80 Hz. First and the last measurement was registered without vibration stimuli. Between these measurements were taken a measurement with vibration stimuli onset.

In vibration stimuli, condition participants stood quietly 10 s. Subsequently, stimulators were set on. Vibration stimuli take 20 s. Postural response registration takes 60 s.

C. Methodology of Measured Signal Processing

Overall postural responses signals - statokinesigrams were provided with the stabilometry platform (Fig. 1 (b)). BTS SMART DX provided kinematics data sets from retroreflective markers. For data preprocessing, raw kinematics markers data sets were interpolated by SMART Analyzer. Stabilometric and kinematics data sets were calibrated in Matlab.

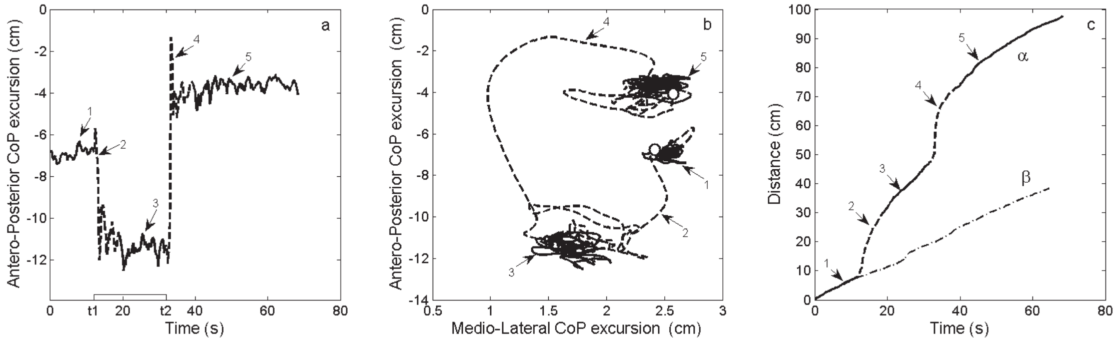

Fig. 1 Representative subject measured data in a situation of eyes open with 80 Hz bilateral vibration stimuli. (a) Stabilogram, (b) Statokinesigram (figure is not proportional, due to visual contrast), (c) Developed statokinesigram trajectory (DST). Full line - pseudo-steady state, dashed line - adaptation. α - DST without vibration stimuli, β - DST with vibration stimuli (dot-dashed line) t_1 and t_2 - beginning and end of vibration stimuli time, respectively

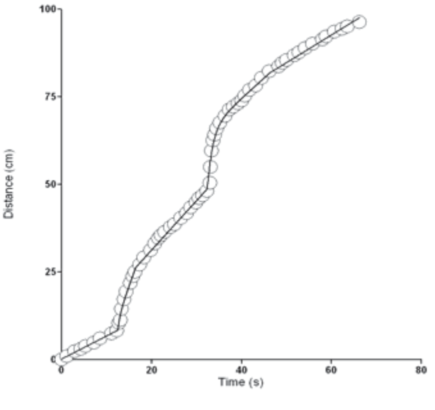

Fig. 2 Model fitting of DST in open eyes situation with 80 Hz bilateral vibration stimuli (circles - reduced measured data, full line - model response)

For data processing were used Matlab and CTDB software. Stabilometric platform measured data processing involves statokinesigram visualization and its decomposition into stabilogram which shows mediolateral and anteroposterior (Fig. 1 (a)) Center of Pressure (CoP) excursion in time dependence. For modeling of human postural responses registered by stabilometry platform, the Method of Developed Statokinesigram Trajectory (MDST) was used. This method is based on the construction of developed statokinesigram trajectory from measured statokinesigram data (Fig. 1 (c)). Optimization of model fitting was realized by Monte Carlo method [9], [10] according to a minimal value of Akaike's information criterion [11] (Fig. 2). The position of retroreflective markers is during data registration three-dimensional registered, so one marker provides with tree column matrix of measured data. One measured channel represents one direction in Cartesian coordinate system.

Two channels constituted a projection of marker position in the horizontal plane was selected for modeling purpose. These data were used for the construction of developed marker data trajectory (DMT) by MDST (Fig. 3).

Regression analysis of developed statokinesigram trajectory with every developed marker data trajectory has been done to reveal the symmetry between two kinds of measured postural responses and to find out which markers best correlate with stabilometry output signal (Fig. 4). The level of symmetry is quantified by scaling coefficient of regression analysis λ (1) and by Pearson's correlation coefficient.

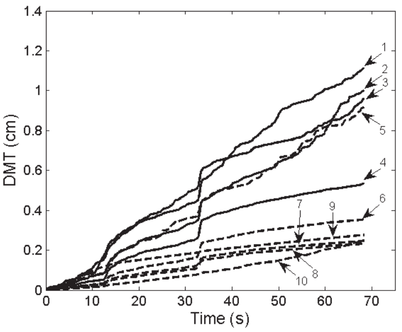

Fig. 3 Developed markers trajectory (DMT) in open eyes situation with 80 Hz bilateral vibration stimuli (1 - head left marker, 2 - head right marker, 3 - shoulder left marker, 4 - shoulder right marker, 5 - hip left marker, 6 - hip right marker, 7 - knee left marker, 8 - knee right marker, 9 - left ankle marker, 10 - ankle right marker)

$$DMT = \lambda DST \pm SD \tag{1}$$

where DMT is developed marker trajectory distance (cm), DST is developed statokinesigram trajectory distance (cm), SD is standard deviation, λ is scaling coefficient.

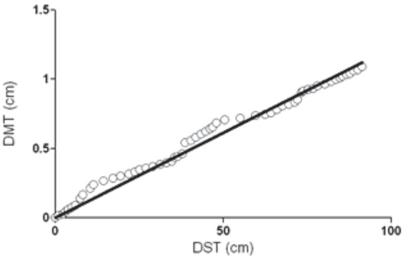

Fig. 4 Linear regression between DST and DMT (left head marker - at Fig. 3 (1 - head left marker), eyes open, 80 Hz vibration stimuli)

III. Results

Results of regression analysis summarized in Tables I and II show a high correlation between DST and DMT. Most of the markers exhibit approximately symmetrical values of scaling coefficient in situations of open and closed eyes. Notable differences exhibit head and shoulders markers, which DMT is in the most of the cases nonsymmetrical according to Sagittal plane and also in the meaning of scaling coefficient (Fig. 5).

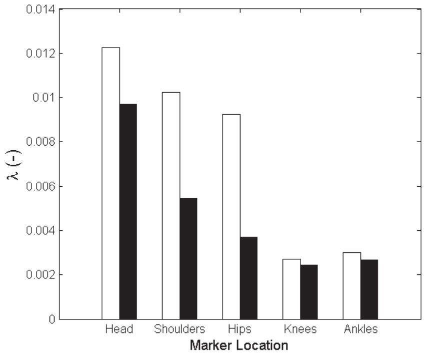

Fig. 5 Scaling coefficients (λ) of markers in open eyes situation with 80 Hz bilateral vibration stimuli (white - left side markers; black - right side markers)

TABLE I
RESULTS OF REGRESSION ANALYSIS BETWEEN DST AND DMT
(EYES OPEN WITH 80 HZ ACHILLES TENDON BILATERAL VIBRATION STIMULI)

Marker	Scaling Coefficient (λ)	Standard Deviation (SD)	Pearson's Coefficient
Head L	0.0123	1.09e-4	0.994
Head R	0.0097	7.89e-5	0.993
Shoulder L	0.0102	6.17e-5	0.997
Shoulder R	0.0054	1.45e-5	0.999
Hip L	0.0092	6.68e-5	0.995
Hip R	0.0037	1.68e-5	0.998
Knee L	0.0027	1.81e-5	0.996
Knee R	0.0024	9.10e-6	0.998
Ankle L	0.0030	3.72e-5	0.993
Ankle R	0.0027	3.60e-5	0.991

L - left side marker, R - right side marker

TABLE II
RESULTS OF REGRESSION ANALYSIS BETWEEN DST AND DMT
(EYES CLOSED WITH 80 HZ ACHILLES TENDON BILATERAL VIBRATION STIMULI)

Marker	Scaling Coefficient (λ)	Standard Deviation (SD)	Pearson's Coefficient
Head L	0.0076	6.03e-5	0.994
Head R	0.0166	1.54e-4	0.991
Shoulder L	0.0087	4.30e-5	0.997
Shoulder R	0.0074	5.30e-5	0.996
Hip L	0.0041	2.58e-5	0.997
Hip R	0.0055	5.48e-5	0.993
Knee L	0.0026	2.60e-5	0.994
Knee R	0.0032	3.28e-5	0.991
Ankle L	0.0018	1.60e-5	0.993
Ankle R	0.0019	2.40e-5	0.984

L - left side marker, R - right side marker

IV. Discussion and Interpretation of Results

It has been shown that DMT is correlated to DSTα. According to values of scaling coefficient, it can be assumed that each body segments have a different contribution to human balance maintain.

Fig. 1 (c) presents two function regimes of the human postural system. DSTα and DSTβ represent regime with and without vibration stimuli, respectively. The behavior of the postural system and its responses in the steady functional regime and in actuated functional regime are different and nonsymmetrical. Due to this feature of postural system responses, it is considered as a nonlinear system.

General postural system transfer function (2) is defined as the ratio of postural system output to postural system input [12]. Input function in steady state is defined as (3). In actuated functional regime is input function defined as (4).

MDST allow identifying the model of human postural system behavior from statokinesigram and its phases of postural balance control (pseudo-steady state represented by the constant velocity of CoP excursion and adaptation on stimuli set on and off). Based on DSTα was formed the mathematical model structure of postural system behavior (5).

$$H(s) = \frac{sD(s)}{I(s)} \tag{2}$$

$$I_1(s) = \frac{1}{s} \tag{3}$$

$$I_2(s) = \frac{1}{s} + \frac{2}{s}e^{-t_1 s} - \frac{1}{s}e^{-t_2 s} = \frac{1}{s}\left[1 + 2e^{-t_1 s} - e^{-t_2 s}\right] \tag{4}$$

where $H(s)$ is general transfer function, $sD(s)$ is the output signal of the postural system, $I(s)$ is the input signal of the postural system, t_1 is a time of vibration stimuli beginning, t_2 is a time of vibration stimuli end, s is Laplace operator.

$$\begin{aligned} sD(s) &= G_1 + \frac{G_2}{1+T_2 s}e^{-\tau_2 s} + G_3 e^{-\tau_3 s} \\ &+ \left(\frac{G_{4i}}{1+T_4 s} + G_{4p}\right)e^{-\tau_4 s} + G_5 e^{-\tau_5 s} \end{aligned} \tag{5}$$

where $sD(s)$ is velocity (cm/s) (derivation of distance in Laplace domain; length of CoP excursion in time (cm)), G_j is gain of j-th balance control phase, G_{jp} is proportional gain of j-th balance control phase, G_{ji} is integration gain of j-th balance control phase, $e^{-\tau j}$ is time delay of of j-th balance control phase, Tj is time constant of j-th balance control phase, s is Laplace operator.

The proposed mathematical model structure was confirmed on all constructed developed statokinesigram trajectories (DSTα), except cases without vibration stimuli (DSTβ). It also confirmed on the most of DMT data sets, but not at all. These facts support the hypothesis that model (5) describes the behavior of the nonlinear postural system in defined condition (4).

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REFERENCES

[1] F.B. Horak, "Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?" *Age and Ageing*, vol. 35, pp. 7-11, 2006.

[2] A. Słupik, K. Jaworski, A. Mosiołek, D. Białoszewksi, "Assessment of the impact of regular pilates exercises on static balance in healthy adult women: Preliminary report," *WASET Bioengineering and Life Sciences*, vol. 2(7), 2015, pp. 1224.

[3] J. W. Kim, Y. R. Kwon, Y. J. Ho, H. M. Jeon, G. M. Eom, "Relationship between static balance and body characteristics in the elderly," *WASET Biomedical and biological engineering*, vol. 1(10), 2014, pp. 14.

[4] D. Abrahamova, M. Mancini, F. Hlavacka and L. Chiari, "The age-related changes of trunk responses to Achilles tendon vibration," *Neurosci lett.*, vol. 467, pp. 220-224, 2009.

[5] A. Polonyova, F. Hlavacka, "Human postural responses to different frequency vibrations of lower leg muscles," *Phisiol. Res.*, vol. 50, pp. 405-410, 2001.

[6] N. Adamcova, F. Hlavacka, "Modification of human postural responses to soleus muscle vibration by rotation of visual scene," *Gait Posture*, vol. 25, pp. 99-105, 2007.

[7] H. Ceyte, C. Cian, R. Zory, P.A. barraud, A. Roux, M. Guerrraz, "Effect of Achilles tendon vibrationn on postural orientation," *Neurosci Lett.*, vol. 416, pp. 71-75, 2007.

[8] B. Barbolyas, J. Chrenova, K. Buckova, M. Cekan, B. Hucko and L. Dedik, "Postural system adaptation to Achilles tendon vibration stimuli - The pilot study," in *7th International Posture Symposium*, Slovakia, 2015, to be published.

[9] E.S. Lee, *Quasilinearization and invariant embedding*. Academic Press, New York, 1968.

[10] I. Manno, *Introduction to the Monte-Carlo method*. Akademiai Kiado, Budapest, 1999.

[11] H Akaike, *Canonical correlation analysis of time series and the use of an information criterion*. In: Mehra RK, Lainiotis DG (eds) System Identification: Advances and Case Studies, Academic Press, New York, pp. 27-96, 1976.

[12] L. Dedík, M. Ďurišová, *System approach in technical, environmental, and bio-medical studies*. Slovak University of Technology, Bratislava, 1999.