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POSTURAL RESPONSE SIGNAL CHARACTERISTICS IDENTIFIED BY METHOD OF DEVELOPED STATOKINESIGRAM

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Abstract. *Human postural system is taken as complex biological system with specific input and output time characteristics, in this study. Evaluation of measured output characteristics is useful in medical diagnostics or in describing postural system disorders. System theory principle provide suitable basis for postural signals analysis. Participating volunteers were instructed to maintain quiet upright stance posture on firm support surface of stabilometric platform for 60s. Postural system actuation was realized by vibration stimuli applied bilaterally on Achilles tendons for 20s. Postural reaction signal, its time profile and static and dynamic characteristics were evaluated by Method of Developed Statokinesigram Trajectory (MDST).*

1 INTRODUCTION

Maintaining balanced upright stance posture is considered as a complex task due to considered involvement of human postural system muscles groups. Where muscles are actuators of skeletal system controlled in biological feedback loop. This idea is involved in model representation in form of inverted pendulum in several research studies [1, 2, 4]. Correct functionality of human balance control and sensory system are essential assumptions of balanced upright stance posture [2]. Quality of human balance control depends for most by the sensory system integration capability. Some studies describe insufficient sensory system integration in combination with overweight or with sensory system disorder [2, 3] as important factor in falling resultant at injuries. Based on already performed observations, young volunteers and volunteers without postural system disorders have better functional limits in body tilting and postural reaction velocity. Properties of particular postural system are often derived from postural reaction signal measured by stabilometric platform (statokinesigram) in clinical praxis. Kinetic and kinematic analysis are also utilized in assessment of human balance control capability. Our previous study deals with description of correlation between postural response time series measured by stabilometric platform and kinematic data measured by motion capture system [5]. Signal measured by stabilometric platform represents Center of Pressure (CoP) displacement in axial plane. Application of appropriate signal analysis methodology is useful in description of human postural system states. There are several established signal processing methods which deals for example with statokinesigram decomposed into two signals (antero-posterior and medio-lateral CoP excursion i.e. stabilogram) analyzed in time domain [3], stabilogram analysis in frequency domain. There are also studies explaining functionality of biofeedback control system governing postural system movement based on system and control theory [1-6]. Presented paper is oriented on application of Method of Developed Statokinesigram Trajectory (MDST) for analyzing complex statokinesigram in time domain. MDST involves construction of time profile characteristics from measured statokinesigram which is shows to be convenient for identification of gain and time constants. Consequently, it is discussed the contribution of MDST to description of particular postural system adaptation capability.

2 MATERIALS AND METHODS

There are six healthy volunteers participated in this study. Volunteers were instructed to maintain bipedal upright stance posture on firm support surface of stabilometric platform with eyes closed. Postural reaction signal registration takes 60s. Bilateral Achilles tendon vibration stimuli takes 20s and it was applied after 10s of quiet stance. Vibration was generated by two DC motors with eccentrically loaded mass. CoP registration was realized by vibration stimuli onset at 20, 60 and 80Hz. Registration of CoP excursion was also realized without vibration stimuli offset before and after vibration stimuli onset measurement season. One measurement season is bind with particular vibration stimuli frequency. Each CoP registration was repeated three times. Sampling frequency of data acquisition was 100 Hz. Measured data was processed by MDST by MATLAB and by CTDB (custom made software - Clinical Trial DataBase). There was constructed Developed Statokinesigram Trajectory (DST) in time dependence after raw measured data reduction in CTDB. From DST was derived gains and time constants of postural system model behavior [5] expressed in form of transfer function (1), where *Y(s)* is output signal, *X(s)* is input signal, K_i are gain in i-th control phase and T_i are time constants in i-th control phase. Input function has feature of step function.

$$Y(s) = \mathrm{H}(s)X(s) \tag{1}$$

$$Y(s) = K_1 + \frac{K_2}{1+T_2 s}e^{-\tau_2 s} + K_3 e^{-\tau_3 s} + \left(\frac{K_{4i}}{1+T_4 s} + K_{4p}\right)e^{-\tau_4 s} + K_5 e^{-\tau_5 s} \tag{2}$$

3 RESULTS

Measured statokinesigrams were processed by MDST and then after analyzed. Purpose of DST analysis is to reveal static and dynamic characteristics of human postural system in situation with disturbed somatosensory information channel in biofeedback control loop. Figure 1 shows standard display of statokinesigram measured in bipedal upright stance posture disturbed by vibration stimuli at 80 Hz. Figure 1 shows also DST relevant to showed statokinesigram. Depicted statokinesigram is divided into five indicative segments of postural system state. There are observed three concentrated regions (Fig. 1). These regions indicate steady state of postural system in stance posture and they are noted by Greek letters ρ, τ, ω. Steady state is characterized by approximately constant velocity of CoP excursion in healthy volunteers in upright stance posture (Fig. 1). There is observed that DST length changes proportionally in time dependence, according to depicted $DST_{A/\rho,\ \tau,\ \omega}$ and DST_B. $DST_{A/\tau}$ is considered as steady state under condition of disturbed biofeedback control loop. Remaining two segments of statokinesigram are characterized by extremely large CoP excursion and they are noted by Greek letters σ, φ. $DST_{A/\sigma,\ \varphi}$ time profile is similar to transient characteristic of first-order linear system. There were identified gains and time

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constants regarding to *DST* time profile for particular segments (Tab. 1). There is observed postural system adaptation at each next trial within one measurement season, regarding to Fig. 2. DST_B depicted for CoP registration in the first trial is showed by solid line, in the second trial by dashed line and in the third trial by dash-dot line. DST_B length has decreasing tendency with trial repeating within one measurement season.

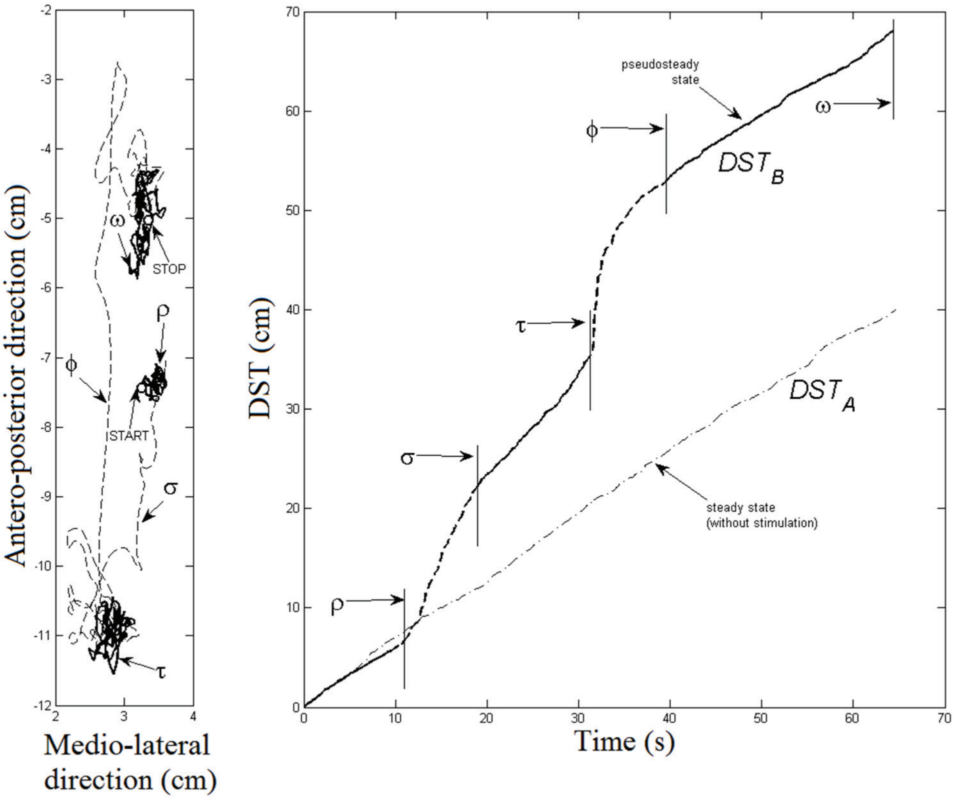

Figure 1: *Statokinesigram measured by bilateral vibration stimuli (20 Hz) located on Achilles tendons in bipedal quiet upright stance posture with eyes open(a) and its relevant DST_B (b).*

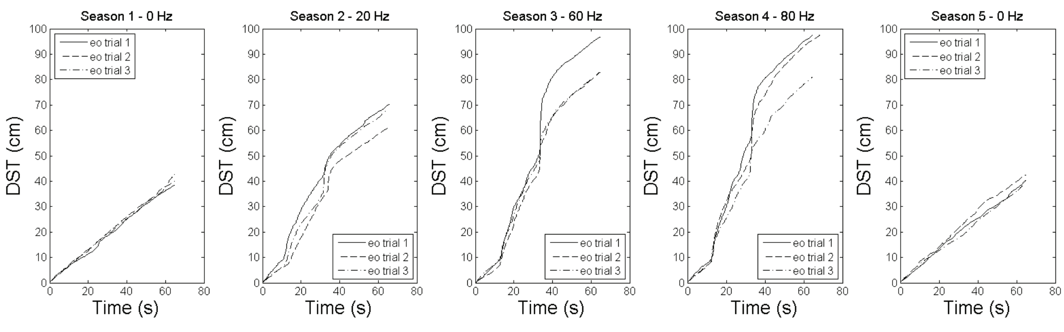

Figure 2: *DST over whole measurement seasons.*

Table 1: *Parameters identified by MDST related to model of postural system behavior.*

Vibration stimuli Intensity (Hz)	Trial	$K_{2(\sigma)}$ (cm/s)	$T_{2(\sigma)}$ (s)	$K_{4i(\varphi)}$ (cm/s)	$T_{4(\varphi)}$ (s)	$K_{4p(\varphi)}$ (cm/s)	Increase of DST length (%)
20	1	2,511	0,695	8,617	4,290	0,049	24,7
	2	1,433	2,067	8,480	1,281	0,054	69,9
	3	1,965	1,966	12,853	0,734	0,053	69,2
60	1	2,528	1,414	20,726	0,505	0,061	113,4
	2	2,064	0,754	14,559	1,401	0,070	146,9
	3	2,188	1,147	10,782	0,950	0,094	81,05
80	1	2,661	0,562	17,735	1,420	0,043	111,7
	2	3,602	0,544	16,862	1,208	0,069	122,8
	3	2,560	0,214	10,211	1,258	0,103	92,2

3 CONCLUSIONS

Postural system actuation by input vibration stimuli represents disturbance in sensory information involved in biofeedback control loop. DST_A and DST_B shows differences in measured postural response signals in situation with vibration stimuli offset and onset, respectively (Fig. 2). DST_B seems to be appropriate for identification of particular postural system dynamic characteristic. Our research has shown application MDST for parameters identification of human postural system model. Proposed model describes dynamical relationship between postural system input and output according to system approach. In the meaning of biological signal processing and understanding, MDST introduce an alternative approach to postural responses analysis as complex statakinesigram in time domain. Identified parameters are suitable for postural system classification and detection of possible disorders related to standard functionality of postural system. It is already observed that man with postural disorder does not have closely concentrated steady state regions in statokinesigram. It is assumed that for man with postural disorder are DST model parameters values as outlier from normal values. Findings depicted in Fig. 2 are consecutive on our previous study [6].

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