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A novel approach in objective assessment of functional postural responses during fall-free perturbed standing in clinical environment

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Abstract. The proposed approach offers few novelties in integration of objective assessment of postural responses when an unexpected perturbation is applied to the standing person into the existing rehabilitation therapy. The research apparatus was equipped with electrical actuators to provide unexpected perturbations (controllable and repeatable strength and duration) to the standing frame in eight directions during quiet standing in a fall-safe environment. During the perturbations ground reaction forces were recorded under each foot and the motion of center of pressure was derived to extract the postural response indicators in time and space domain. Seven neurologically intact subjects participated in normative set up that was used to develop an algorithm for selective postural response characteristics analysis for each perturbation direction. The postural responses in two incomplete spinal cord injured persons and hemiparetic stroke patient were investigated and contrasted to the normative responses to test the proposed approach. The outcomes of the investigation showed expected distinctive direction-dependent postural responses characteristic for hemiparetic subjects. Our observations suggest that the approach may become effective in substantial quantitative multidirectional stabilometric evaluation of functional postural responses, especially when the effectiveness of the balance training rehabilitation program is in need for objective evaluation. Simultaneously the apparatus can be used also for the balance training and therefore become a training and assessment tool for clinical and home environment.

Keywords: Postural response, clinical assessment, balance training, center of pressure, neurological rehabilitation

1. Introduction

The principle of "evidence-based rehabilitation" requiring objective evaluation of functional capabilities before and after intervention is becoming increasingly important as it facilitates optimization of interventions as well as the outcome of rehabilitation process in each individual patient. Efficient balance and postural control is one of the most important functional abilities that are prerequisite for more complex functional tasks. Currently, the assessment of postural control and balancing abilities is predominantly done by various clinical tests that are subjectively scored by healthcare professionals. Berg's Balance Scale (BBS) [2] is the most accepted and widely used as it is reliable, exhibits very good within- and between-rater agreement and can be used as a reliable predictor of potential fallers. However, clinical tests cannot provide insight into particular mechanisms of postural control, that can

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be obtained by studying kinematics, kinetics and dynamic electromyography of selected muscles during postural responses elicited by various perturbation modalities [10]. These modalities predominantly include moving [11,14] and rotating standing platforms [1] with different strategies and perturbation techniques [4]. A few existing clinically approved devices, based on moving standing platforms (e.g. Balance Master – NeuroCom Inc., Balance Quest – Micromedical Technologies Inc.) enable detailed examination of several aspects of postural control under different sensory conditions. These devices are large, use fixed safety-support frame or safety harness and need dedicated laboratory space thereby representing a considerable financial investment that prohibits their wide use.

In the recent years a research apparatus for postural balance assessment, that in contrast to moving and rotating platform perturbation principles, delivers perturbation by applying force on the pelvis, while the subject is standing on firm surface has been developed [12]. In this way the perturbing apparatus accompanies postural sway of subject, due to it's limited range of movement prevents fall without additional supporting aid (body weight support or handles, etc.) and delivers perturbation in any direction in the transverse plane. The apparatus without any actuator and based only on passive controllable spring defining the stiffness of the two-degrees of freedom standing frame has become a clinically approved assisting device for balance training (BalanceTrainer™, commercial marketing Medica Medizintechnik GmbH, Germany) and in use in several rehabilitation centers worldwide [13]. Implementation of the research apparatus application capabilities into the improved lightweight frame resulted in new clinical approach offering in addition to balance training also postural responses assessment. The patients entering the balance training rehabilitation program using BalanceTrainer™ have been in addition to clinically well accepted but subjective BBS in a need for objective and direction distinctive evaluation indicator. Likewise the physician can use the direction distinctive postural response information to evaluate the effectiveness of the balance training program for each direction and with special attention to the subject's affected side.

Considering the clinically well accepted balance training program and possible frame upgrade with ability to assess postural responses a new method that does not require special technical expertise is proposed. The proposed approach uses the new apparatus to assess postural responses and objectively evaluate the assessed set of responses for each perturbation direction by providing simple enough and understandable information. The objective of this paper is to present such approach for objective assessment of directional postural responses and demonstrate the applicability of the proposed method. We have assessed a set of normative postural responses in a group of neurologically intact individuals and derived a set of postural responses indicators. We further examined postural responses in three neurologically impaired subjects and contrasted them to the normative data in order to explore its clinical applicability.

2. Methods

2.1. Subjects

In the normative assessment 7 neurologically intact volunteers ranging in age from 24 to 32 years (all male, 26.6 $\pm$ 3.1 years, 178.3 $\pm$ 6.3 cm and 71.4 $\pm$ 7.9 kg) and in the clinical investigation 3 patients in chronic stage (all male, 53.3 $\pm$ 10.4 years, 175.7 $\pm$ 11.0 cm, 85 $\pm$ 7 kg) with known neurological disorders (incomplete SCI Th-3-4-5, 18 years ago; Th osteoporosis, pathological SCI 3 years ago and one was hemiparetic, stroke) participated. The criteria for participation was: 1) no neurological and musculoskeletal impairments that may affect balance for the volunteers and 2) ability to stand and keep

Table 1
Subjects, mass, height and perturbation parameters

Subject	Age	Weight	Height	Neurological Disorder	Perturbation amplitude
P1	25	67	172	–	strong
P2	32	64	174	–	strong
P3	25	71	177	–	strong
P4	24	66	182	–	strong
P5	25	69	180	–	strong
P6	30	76	173	–	strong
P7	25	87	190	–	strong
P8	65	77	165	incomplete SCI, Th osteoporosis	weak
P9	45	90	187	incomplete SCI,Th 3-4-5	strong
P10	50	88	175	stroke, hemiparesis	middle

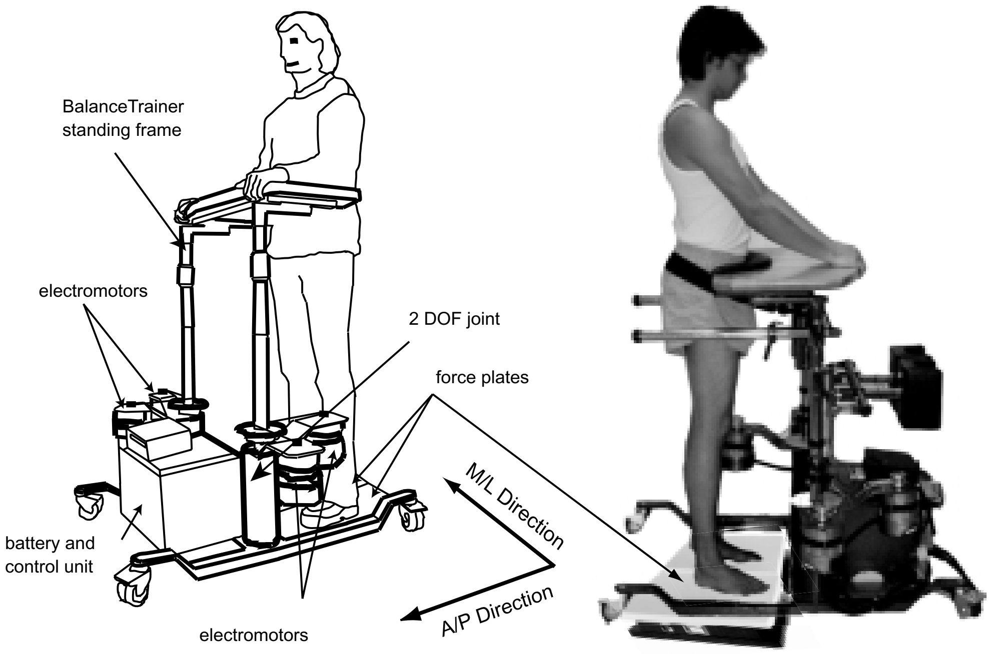

Fig. 1. Schematic presentation and photograph of apparatus for assessment of postural responses in clinical practice.

balance in the balance training apparatus for subjects with neurological disorders. The data on the subjects are given in Table 1. The methods used in this study were approved by local ethics committee at the Institute for Rehabilitation, Republic of Slovenia and the subjects gave informed consent.

2.2. Equipment and protocol

The apparatus is made of steel base construction placed on four wheels, which when unlocked enable the apparatus mobility. The later is important in clinical environment where the rehabilitation aids have no dedicated space. The standing frame is made of aluminium and fixed to the base with passive controllable spring defining the stiffness of the two degrees of freedom (2 DOF) standing frame. On the top of the standing frame a wooden table with safety belt for holding the subject at the level of pelvis was mounted (Fig. 1). Four battery powered electro-motors (Iskra Avtoelektrika d.d., šempeter, Slovenia) were mounted in the base of the apparatus to generate postural perturbations of the standing frame in eight major directions (forward, forward-right, right, back-right, back, back-left, left and forward-left). Four steel wires connected the vertical rods of the standing frame and the shafts of electro-motors. A control unit with fast safety thermal cutouts for each motor together with a personal computer equipped with National Instruments (NI-MIO64E) Board were supervising the apparatus and simultaneously managing the data assessment. Subjects stood with each foot on separate force plates (AMTI OR6-5, AMTI Inc., Watertown, MA, USA) assessing 6-DOF data (3 forces, 3 moments, filtered within AMTI amplifier, A/D sampling frequency 100 Hz).

Computer software generated pulses eliciting perturbation in one of the four principal directions (Forward – FW Right – RT, Left – LT and Backward – BW) or in one of the four combination of the principal directions (Forward/Right – FR, Backward/Right – BR, Forward/Left – FL, Backward/Left – BL). The realization of perturbation in a combined principal direction was managed by simultaneous action of two electro-motors each for the corresponding principal direction. The perturbation power (three levels: weak, medium, strong, depends on the pulse duration) was selected according to the subject's balance ability. Neurologically intact subjects' postural responses when exposed to strong perturbation were within an acceptable range, none of the subjects expressed any inconveniences or showed difficulties during recovery from the perturbations. Therefore the strong perturbation amplitude was selected. The perturbation strength in neurologically impaired subjects was selected with gradual attempts to bring the postural response to the comparable level. If the subject managed to achieve a postural response amplitude within limits assessed in healthy subjects and the subject did not feel uncomfortable, the perturbation strength was considered appropriate, otherwise the subsequent strength was attempted until found acceptable. The selected perturbation strengths are presented in Table 1. The time instant of perturbation commencement which was unknown to the subject, was 1 s (user set up) after the operator pressed the button. The total time of data assessment was set to 6 s due to longer perturbation response recovery time in neurologically impaired subjects.

Prior to the postural response assessment the apparatus reliability and repeatability were examined. The time-delay difficulty arose due to slack steel wire that commands electro-motors and standing frame. The time-delay was considered as the time elapsed between the moment when the electric pulse for perturbation commencement was delivered to electro-motor and the moment of actual perturbation. A one-way analysis of variance, ANOVA [17] was performed to confirm that the time-delay was independent of perturbation direction and the measurements were therefore repeatable. The dependent variable was the time-delay, while the independent variable were the eight perturbation directions.

Each subject that participated in postural response data assessment took part in 32 consecutive trials, 4 for each direction. Perturbations were delivered in random order under the experimental conditions given in Table 1. Subjects were instructed to stand upright prior to the perturbation, comfortably side-by-side in normal standwidth position [18] with feet in parallel, each on separate force plate in a way that the ground reaction force is distributed symmetrically among both sides, if that was possible and try to attain the same posture when recovering from perturbation.

2.3. Data analysis

For each perturbation trial a set of 6 DOF data (forces and moments in x (anterior-posterior direction; A-P), y (medial-lateral direction; M-L) and z (vertical) axis) for each foot were recorded using two force plates. Common vertical force (vertical ground reaction force, GRF) norm ($\|F_z\| = \frac{F_z}{m}$), under both feet

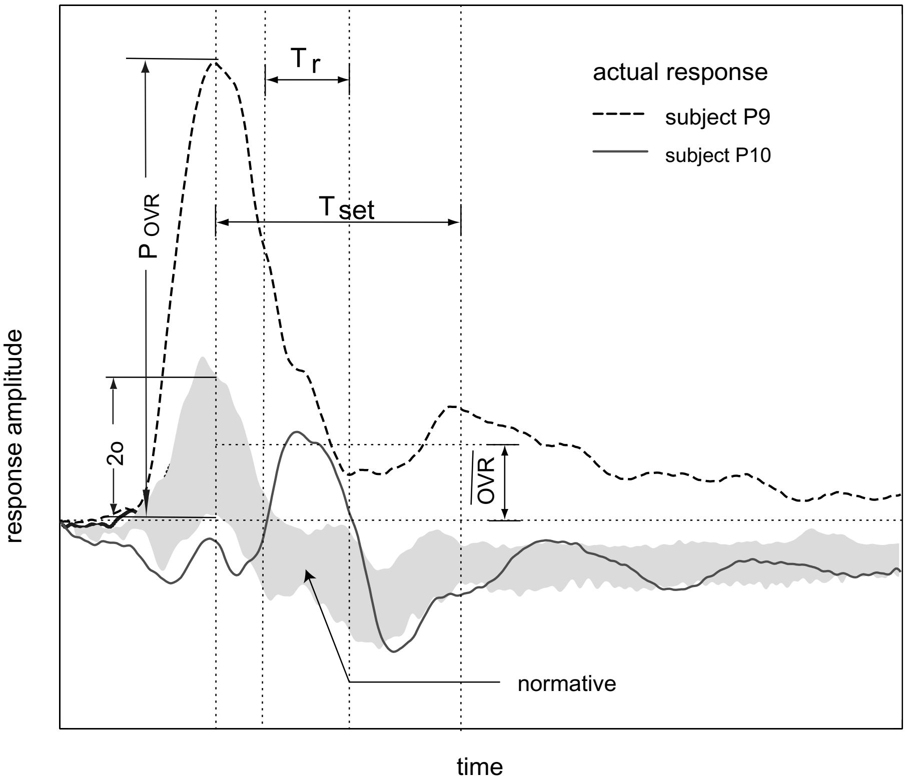

Fig. 2. Evaluation values: a delayed response time (T_r [ms]), and response amplitude overshoot (P_{OVR}). $\overline{OVR}$ is the mean overshoot of all neurologically intact subject). The T_r was defined as a time delay between normative and actual response. Settling time (T_{set} [ms]), the time between the instant of the response maximal overshoot and the instant when the CoP response stabilize within 10% limits.

has been frequently used for the analysis of balance [15]. Additional information was found in center of pressure (CoP) as the calculation took into account moments in A-P and M-L direction. Sampled (100 Hz) and filtered (4th order Butterworth filter, 15 Hz cut-off frequency) data from each force plates were transformed from local coordinate system located at the center of each force plates to the global coordinate system applying the following equations (Eqs (1)–(2)):

$$\mathbf{r}_i = \mathbf{R}_i + \mathbf{r}_i^{'} \tag{1}$$

where $\mathbf{R}_i$ is the vector from global to local frame, $\mathbf{r}_i$ is the vector of CoP coordinates of each force plate in global coordinate system and $\mathbf{r}_i^{'}$ is the vector of CoP coordinates of each force plate in local frame.

$$\begin{aligned} \mathbf{M} &= \sum_i (\mathbf{r}_i \times \mathbf{F}_i) = \mathbf{r}_L \times \mathbf{F}_L + \mathbf{r}_R \times \mathbf{F}_R \\ \mathbf{F} &= \sum_i \mathbf{F}_i = \mathbf{F}_L + \mathbf{F}_R \end{aligned} \tag{2}$$

The common CoP was then calculated [19] using transformed moments and forces in global coordinate frame. The global coordinate frame was transformed using homogenous transformation [16] to the new

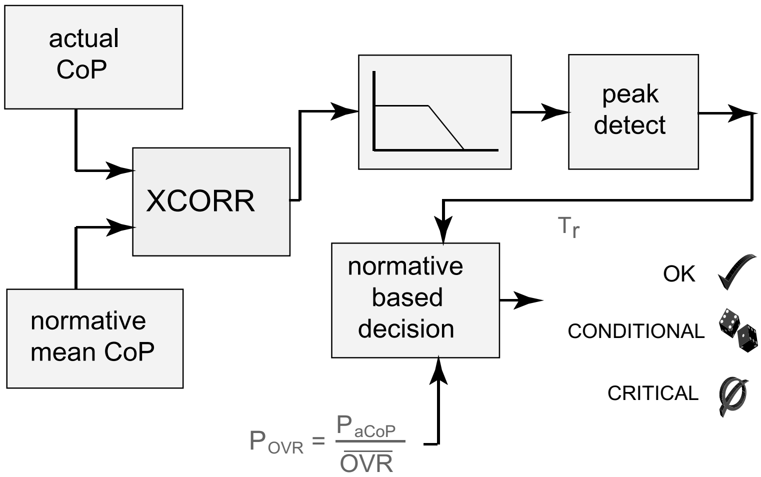

Fig. 3. Block diagram of the automated directional postural response evaluation. The assessed CoP is compared (crosscorrelation – xcorr) with the reference (or normative) and the outcomes as amplitude and time-delays are sorted upon the decision based algorithm (conditions). The status of postural responses in each direction is available to the clinical users – ok, conditional or critical.

position determined by the starting point of the CoP (**d** = [CoPx(0) CoPy(0)]) while keeping the same orientation ($\mathbf{R} = \mathbf{I}$).

The computed mean ($\overline{CoP}$) and the standard deviation (σ) of the CoP in the group of neurologically intact volunteers were used to built up a normative. The normative set of data was based on overall mean and 2σ and served as a reference in further analysis of the data assessed in each individual neurologically impaired subject in space and time domain. The space domain was suitable for both type of analysis; on-line during the assessment and off-line visual presentation. But the space domain also lacks of timing information, latencies and signal amplitudes for each perturbation direction and the direction of recovery from the perturbation. Therefore some postural responses may turn out very similar in space domain, but different in time domain. Thus the information in space domain was not sufficient and was supplemented with CoP time-course, normative and two major evaluation values, quantitatively evaluating the difference from the normative (Fig. 2): a delayed response time (T_r [ms]), and response amplitude overshoot (P_{OVR} [% $\overline{OVR}$], where $\overline{OVR}$ is the mean overshoot of all neurologically intact subject). The T_r was defined as a time delay between normative and actual response. The response amplitude overshoot P_{OVR} was defined as maximal overshoot in first response to the perturbation expressed in percentage of the normative mean overshoot ([% $\overline{OVR}$]). The optional value for evaluation remained the settling time (T_{set} [ms]), the time between the instant of the response maximal overshoot and the instant when the CoP response stabilize within 10% limits.

After the postural responses had been assessed and the evaluation values determined, two conditions originating from the normative were set:

$$100\% - \sigma \leqslant P_{OVR} \leqslant 100\% + \sigma \quad (3)$$

$$T_r \leqslant \sigma[ms] \; (200 \; ms) \quad (4)$$

When both conditions (Eqs (3) and (4)) were fulfilled, the postural response was considered OK. If only one condition was true, the response was considered acceptable, but alerting. Therefore more

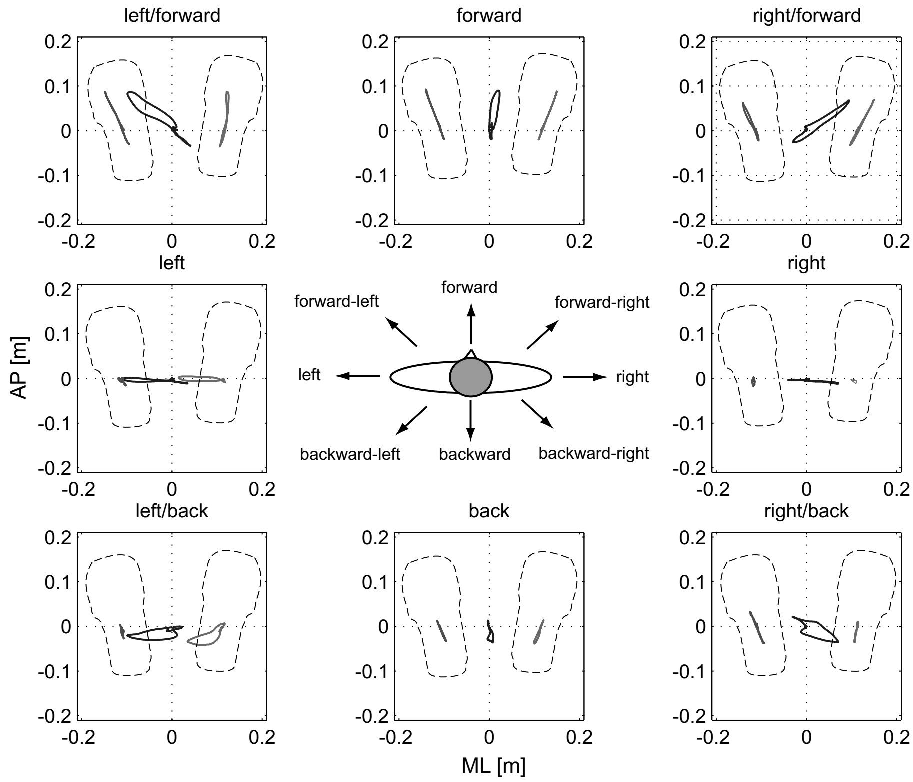

Fig. 4. CoP for healthy subject P6. For each perturbation direction the CoP under both feet is presented as well as the common CoP.

detailed graph analysis was suggested before making decisions on response status. When none of the above conditions were true, the directional response was assigned as critical. Exceptions were responses in perpendicular directions (e.g. AP in RT direction), where the overall movement was not significant (e.g. $\overline{OVR} < 1$ cm). Those responses are neglected in automated evaluation (Fig. 3).

3. Results

3.1. Reliability and repeatability of perturbations

The time-delay between perturbation commencement and actual perturbation of the frame (averaged in 6 subjects, 4 trials and 1 subject 3 trials in total, 208 measurements in total) consistency was tested using ANOVA. The statistical hypothesis testing the differences between time-delays has proven non-significant ($P = 0.143$, criteria for significance $P < 0.05$).

3.2. Center of pressure during postural perturbations

Figure 4 presents the center of pressure (CoP) of both feet for each perturbation direction as well as the common CoP. In the figure the data of a healthy subject P6 is presented and demonstrate the CoP under each foot as well as the common CoP. Subject P6 recovered from perturbation on the same CoP

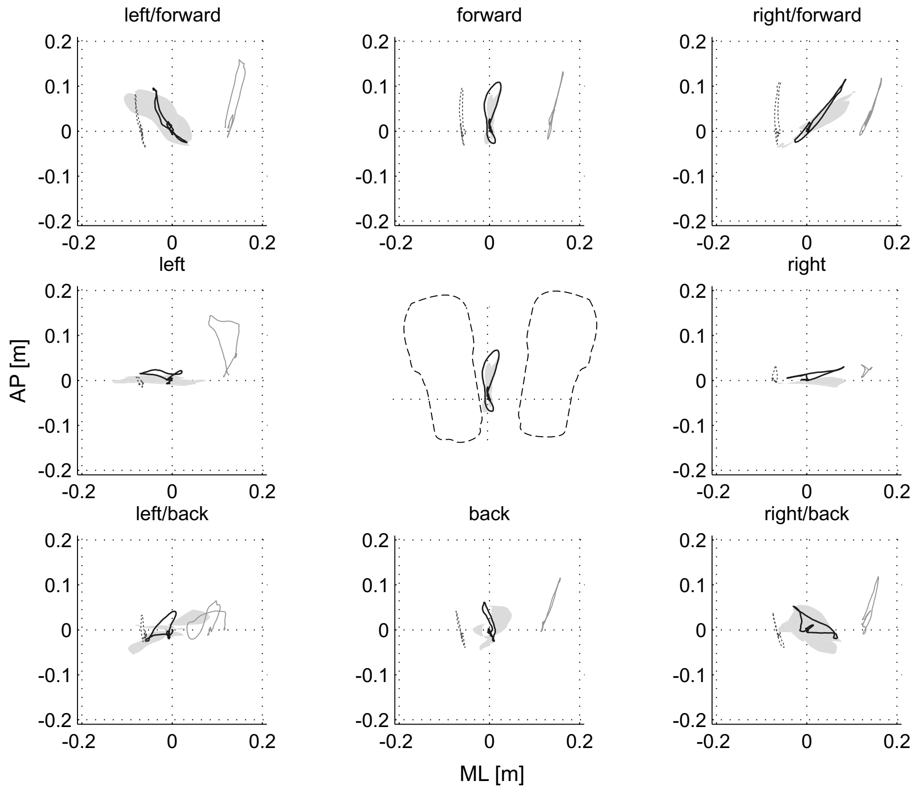

Fig. 5. CoP normative (standard deviation – shaded) computed from the group of healthy subjects. The mean CoP (4 trials each direction) of the subject P8 (solid line) is presented for each perturbation direction. Additionally the CoP under the left (dashed) and right (solid lighter) foot are presented. The feet position with CoP in FW direction is presented in the center.

track or with minimal directional error. The Fig. 5 presents the contrast of the mean CoP (4 trials in each direction) assessed in neurologically impaired subject P8 to the CoP normative. Subject P8 demonstrated directional deviations from the normative in FR and RT directions. The central graph indicates that the subject was standing asymmetrically to the common CoP and that the subject's weight distribution was shifted to the left side (Fig. 6).

Time related events are presented in time-domain in Fig. 6 where the CoPs of the neurologically impaired subjects were contrasted to the normative. The characteristic values (response delay and amplitude) of selected participating subjects are shown. According to the upper middle graph (FW perturbation, CoP in A-P) no significant differences in the neurologically impaired subject were noticed, while oscillation during recovery from the perturbation were significant in CoP of M-L direction (center graph). The middle left graph (LT perturbation, CoP in M-L) shows delayed response in subject P10, but no deviations from the normative for others. In the CoP A-P, the perpendicular axis to the perturbation direction, significant overshoots (P8, P9 – P_{OVR} [% $\overline{OVR}$] $=$ 80% – 250%) and delayed response (P10) can be noticed. The overshoot in upper right graph (P_{OVR} [% $\overline{OVR}$] $=$ 300%) is considered as a consequence of the weight transfer as the amplitude of the response was low ($\overline{OVR} =$ 0.5 cm). The hemiparetic subject P10 showed noticeable time-delays in postural responses (middle right graph: $T_r \sim 505$ ms) in directions the right leg was the key of postural balance and over- or undershoots (P_{OVR} [% $\overline{OVR}$] $=$ 67% – 89%) were noticed while recovering from the perturbation in all other directions.

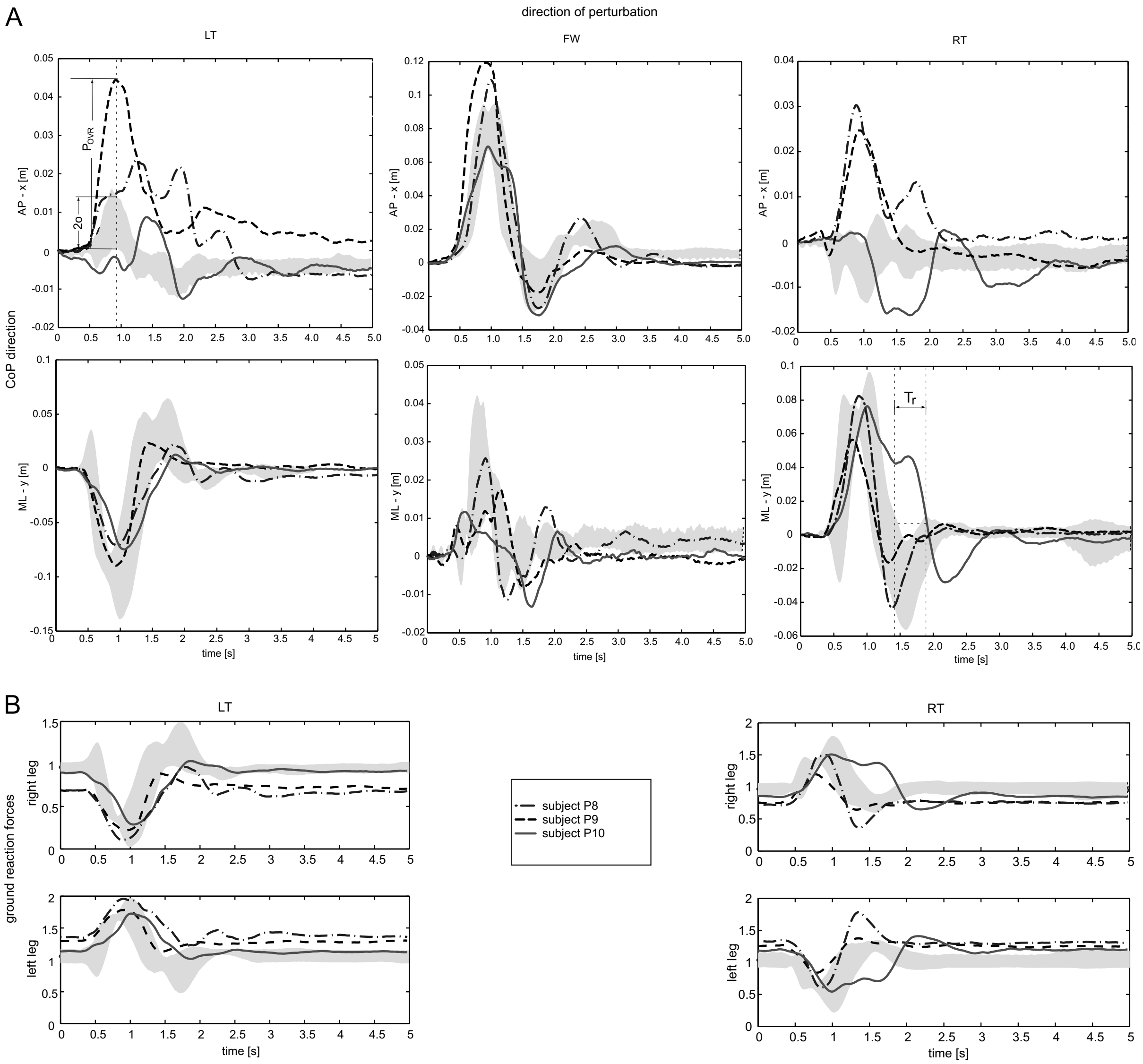

Fig. 6. **A**. The figure shows time-courses of CoP in both planes x (A-P) and y (M-L) for the perturbations in FW, LT and RT directions. In the CoP A-P, the perpendicular axis to the perturbation direction, significant overshoots (P8, P9 – P_{OVR} [% $\overline{OVR}$] = 80% – 250%) and delayed response (P10) can be noticed. The hemiparetic subject P10 showed noticeable prolonged postural responses and delays (P_{OVR} [% $\overline{OVR}$] = 103%, $T_r = 505$ ms) in directions the right leg was the key of postural balance and over- or undershoots (P_{OVR} [% $\overline{OVR}$] = 67% – 89%) and time-delays ($T_r = 23 - 200$ ms) were noticed while recovering from the perturbation in all other directions. **B**. Vertical ground reaction forces (normalized to subject's mass $\frac{\|F_z\|}{m/2}$) where similar deficits can be noticed present a complementary information for each foot in corresponding perturbation direction (LT, RT).

In Table 2 subject P10 data contrasted to the CoP normative are presented. The evaluation values P_{OVR} and T_r were determined for AP and ML directional responses in all perturbation directions. Slightly decreased response amplitudes were noticed in FW (in AP direction 78% of normative mean) and FR (in ML direction 79% of normative mean) directions. Considering the standard deviation σ at

Table 2
Subject P10 data contrasted to the normative $\surd$ - OK $\triangle$ – conditional X – critical

CoP direction	Parameter	FL	FW	FR	LT	RT	BL	BW	BR
AP	P_{OVR} [% $\overline{OVR}$]	**89**	**78**	92	0	300	154	100	85
	$\overline{OVR}$ [cm]	8.8	8.8	7.8	0.6	−0.5	−2.4	−3.8	−4.1
	σ [% $\overline{OVR}$]	5	8	16	66	200	125	21	30
	T_r [ms]	**200**	23	0	–	**350**	**300**	**430**	**750**
	T_{set} [ms]	2350	2302	2005	–	–	2100	1912	1807
ML	P_{OVR} [% $\overline{OVR}$]	**75**	67	**79**	**64**	103	**73**	76	**68**
	$\overline{OVR}$ [cm]	−9.3	1.8	9.9	−11.8	7.4	−8.9	1.7	7.2
	σ [% $\overline{OVR}$]	12	50	9	11	6	8	176	8
	T_r [ms]	196	–	140	168	**505**	85	–	**454**
	T_{set} [ms]	2105	1100	1503	1612	1501	1434	2110	1450
		$\triangle$	$\surd$	$\surd$	$\triangle$	X	$\triangle$	$\triangle$	X

the undershoot instant ($\sigma = 9\%$) the response was assigned as OK (tick mark). The subject P10 was suffering from right side hemiparesis noticeable as time-delays or prolonged postural responses in RT and BR directions (Fig. 6 and in RT and BR column of Table 2). The response to the perturbation in RT direction was delayed for $T_r = 505$ ms in principal movement direction ML and for $T_r = 350$ ms in AP direction. Similar results were found in BR direction. In AP and ML significant response delays ($T_r = 750$ ms, $T_r = 454$ ms, respectively) were present. In ML direction also the response undershoot was significant ($P_{OVR} = 68\%$). Both perturbation directions were assigned as critical for the subject P10 (marked X). In other perturbation directions (FL, LT, BL and BW) no significant values were found. FL direction was conditionally acceptable as response delays were critical. The response undershoots in FL and LT were within 10% ($P_{OVR} \pm \sigma$ ~100%). In BL and BW direction response delays were found ($T_r = 300$ ms, $T_r = 430$ ms, respectively), a reason for conditionally acceptable assignment (triangle mark).

Vertical ground reaction forces in Fig. 6 (lower graphs) display the weight transfer. All GRF ($\|F_z\|$) were normalized on subject's mass, where 1 in the ordinate axis was assigned for equal weight balance. All subjects with neurological disorders involved in clinical investigation suffer from asymmetrical motor functions and consequently the weight distribution was shifted to the less affected side (left).

4. Discussion

A novel approach in objective postural response that can be combined with clinically well recognized balance training was presented. The apparatus perturbation timing was statistically evaluated to test the assessment repeatability and confidence in the postural response method reliability. The outcome of the statistical analysis indicated that the time delay between the moment when the electronic pulse was delivered to the apparatus and the instant of actual frame movement was irrespective of the perturbation direction. The postural response objective evaluation method of individuals in clinical environment was based on CoP assessment. A postural response normative based on neurologically intact volunteers was set up to demonstrate a foreseen application. After the normative had been set, the three participating neurologically impaired persons postural responses were contrasted to the normative data to explore possible clinical applicability.

4.1. Center of pressure during postural perturbations

A CoP has been often considered as an effective tool for postural balance, postural responses and postural threat [5] display. The display in the space domain (Figs 4 and 5) was considered as an on-line assessment tool offering the overview of CoP distribution for left and right and the common CoP response to each directional perturbation. After each perturbation a directional display apprise the operator of response adequacy that also confirmed the fact that the subject did not move or lift his feet. And after the set of all eight directional responses a complete eight-directional space-domain presentation including the set-up postural response normative was given. Here the testing normative was built from data assessed in seven neurologically intact persons. When the data assessed in neurologically impaired person were contrasted to the normative (Fig. 5) functional disorders as an oversized loop or a directional misalignment could be noticed for each perturbation direction. As demonstrated the subject P8 who's right side was functionally affected (hemiparesis) transferred the load to the left extremity and consequently tended towards forward direction when exposed to the RT and FR perturbation direction. That is more evident from the quantitative approach in time-domain. This approach offered comprehensive information for objective assessment of subject's functional balance and response disorders. Such evaluation was based on two values, the overshoot and the response delay when assigned for the CoP in both, the AP and the ML direction for each perturbation direction in subject's data contrasted to the appropriate normative time-course (Fig. 6). The neurologically impaired subject (hemiparetic P10, right) showed increased latencies and amplitude under- and overshoot in response to RT perturbation direction and oscillation of the CoP during recovery from the perturbation in the LT direction, especially in sagittal plane. Those findings indicated a decreased ability to maintain balance during the perturbation also in other planes not only the imposed direction. Similar observations were found in other neurologically impaired subjects [11]. The demonstrated latencies and amplitude under(over)shoots of the CoP were quantitatively evaluated (Fig. 3) and sorted in Table 2.

4.2. Implications for clinical practice

The clinical practice has been in need for objective assessment tool that will supplement the subjective tests that have been in use for a decade [10]. Furman [7] reported that the objective posturography provide information of impact on balance difficulties on various activities. In contrast some authors [6] disagreed and suggested that posturography may not provide information beyond the one provided by standardized clinical test [2,3]. Anyway, the results of the present investigation show that the proposed approach can provide reliable information on balance status of particular individuals, which incorporates directional aspects of postural control and evaluate the effectiveness of the balance training. This way the critical direction can be identified and targeted within therapeutical intervention. The time needed to collect a complete set of postural responses is similar to the time needed to assess BBS.

Values (marked bold) from the Table 2 were subject of evaluation by automated algorithm (Fig. 3) based on conditions in Eqs (3) and (4) indicating postural response disorders for the individuals in each perturbation direction. The assigned remarks indicating an inadequate responses demonstrate directions which may be critical for balance impaired person who may present a potential faller. These associations are significant for a clinical report that can be issued before and after the rehabilitation procedure. Such clinical service may reach even higher efficiency level when data are not compared indirectly, i.e. before and after the balance training with the normative, but a direct cross comparison between pre- and post-training assessment is performed. In practical terms the normative can be replaced by data assessed before entering the balance training program.

The results of the clinical assessment applying the proposed approach are encouraging and offer new opportunities for the objective clinical evaluation of neurologically impaired subjects. The data assessed in each individual subject provide enough information for skilled personnel to objectively evaluate the subject's postural response abilities and eventually evaluate the recovery of standing balance after stroke [8,9] or other neurological disorder. The results obtained in three patients demonstrated the possible application, but to confirm the clinical applicability a more extensive clinical research on two groups of patients, control and experimental group, is mandatory and is already in progress. In the future the currently used fixed laboratory based AMTI force plates can be replaced by mobile standing assessment platforms (AccuSway$^{\mathrm{PLUS}}$ – AMTI Inc.) or even simplified own-built platforms to increase the mobility of the easy-to-use device that guarantees fall-safe postural responses assessment and force the subject into active cooperation as no fixed supporting aid (body weight support, handles, safety harness etc.) is available. Thus the apparatus that in fact can be used also as a balance training device may be located at remote center or even on subject's home and provide assessed data to the specialized consultant via broadband internet.

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