Recent Innovations in Mechatronics (RIiM) Vol. 4. (2017). No. 1.
DOI: 10.17667/riim.2017.1/1.

Directional ratio: a proposed new variable of dynamic balance regain

Bálint Petró, BSc
Department of Mechatronics, Optics and Mechanical Engineering Informatics
BUTE
Budapest, Hungary
petro.balint@gmail.com

Rita M. Kiss, Dsc
Department of Mechatronics, Optics and Mechanical Engineering Informatics
BUTE
Budapest, Hungary
rita.kiss@mogi.bme.hu

***Abstract*— The use of a free oscillating platform for balance training is widespread. However, there is a lack of variables used when analyzing these measurement results. The aim of this study was to introduce and evaluate a new variable. The directional ratio is the ratio of total length of oscillation travelled in the direction parallel and perpendicular to perturbation, respectively. 21 adult figure skaters (m. age 28) participated in balance regain tests, adopting two-legged and one-legged stances on each leg on the PosturoMed platform (Haider Bioswing, Weiden, Germany) with a medial-lateral perturbation. Overall the directional ratio showed weak correlation with the damping ratio (r = -0.05) and the time of balance regain (r = -0.08), suggesting new information content. One-legged stances had significantly lower damping ratio (p = 0.013) and directional ratio values (p < 0.00), showing more anterior-posterior movement and elliptical trajectories. Using the damping and directional ratios together, balance regain can be better characterized in the future.**

Keywords*— *balancing strategy, balance regain, PosturoMed, Figure skating.

I. INTRODUCTION – HUMAN BALANCE IN LITERATURE

The maintenance of balance, especially in the case of bipeds such as humans is an intricate process carried out by an integrated neuro-musculo-skeletal system. Static balancing is examined in the field of posturography whereas dynamic balancing corresponds to the study of all movement [1]. Dynamic balancing can be further categorized as reactive, predictive and anticipatory [2]. Predictive strategies arise from cognitive processes. Reactive and anticipatory functions play a role in repetitive actions and there is an involuntary transition between these coordinative patterns [3].

A. Forms of balance assessment and training

Various methods had been developed for the assessment of balancing abilities. These methods can be categorized by the surface or platform that the participant is standing on. Measurements conducted on solid ground or on an immobile force measuring plate are alike standard posturography measurements. Such methods also involve a sudden perturbation on the body and the resulting balance recovery is recorded [4,5]. A majority of balance assessment methods are based on the balancing board. Balancing boards are freely mounted on a medio-lateral or antero-posterior pivot and subjects must stand on the board maintaining balance for a set amount of time. Balancing proficiency is measured either by the time of successful balancing or by the error of angular position from the horizontal plane in degrees [6].

Another method is based on oscillatory platforms that can move in the horizontal plane. These platforms can provide different balancing tasks. Using a continuous, sinusoidal perturbation allows for studying balance learning and effects of anticipation in a recurrent task [7]. One such study found that the possibly changing synergic connection between muscles allows for maintaining balance at a lower activity level [8].

A free oscillatory platform utilizes a sudden lateral perturbation, after which the participant has to regain their balance, damping the oscillation and stopping the motion of the platform. The speed of oscillation depends on the spring setting. Our study operates with such a device called PosturoMed (Fig. 1).

B. Usage of PosturoMed in literature

In one of the earliest reported PosturoMed measurements, participants adopted one-legged stance with an upright posture on the platform. They repeated measurements both with an ML and AP perturbation. The number of recorded oscillations in these directions gives a quotient named “balance index”. They concluded that such an index would prove useful for quantitative assessment of balancing [10].

DOI: 10.17667/riim.2017.1/1.

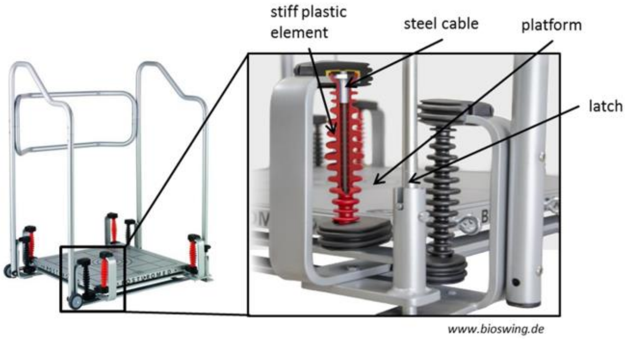

Fig. 1. PosturoMed device [9]

Another study also used both ML and AP perturbations, and defined the end time of balancing as the quantitative performance indicator. The balance regain is successful when motion of the platform is within ±2 mm of the resting position [11]. One study examined the intra- and inter-day reliability of PosturoMed measurements. They found a good relative reliability and revealed few cases possible affected by learning the task [12].

Another study used EMG and an optical motion tracking system with markers attached to the subject's body and the platform [13]. Joint angles were calculated and used to identify the "corrective action" and the ankle, knee and hip strategies of balance regain.

As the subject's balancing efforts are acting as the damping in this mechanical system, Lehr's ratio (damping factor or damping ratio) was introduced to quantify this action [14]. This value compares the actual damping of the system to the critical damping that which cause the system not to oscillate. As such, the damping ratio can be given as a percentage value where higher values represent higher damping properties. Further studies with PosturoMed have been carried out in the field of clinical orthopaedics. Using Lehr's ratio as the performance indicator, the effects of orthopaedic conditions such as knee and hip osteoarthritis and arthroplasty on balancing ability were examined [15,16]. This method had also been used in early post-operative tracking of balancing activity with respect to different (ie. conventional and minimal invasive) surgical methods [17,18].

II. Methods and Material

A. Participants

Adult figure skaters participated in this study. The group included 9 males and 12 females, having a total of 21 participants. Mean age was 28.1 (*4.93) years. Mean bodyweight was 60.65 (*9.48) kg.

B. Platform and measurement

The free oscillating platform PosturoMed® (Haider Bioswing, Weiden, Germany) was used with a medial-lateral perturbation applied. The device is widely used in Europe to train athletes, provide rehabilitation, therapeutic and evaluation methods. The platform is a solid metal plate (12 kg, 60 cm × 60 cm) manufactured with anti-slipping surface that is suspended on eight 15 cm long identical steel springs. This allows the platform to freely move along the horizontal plane. A fastening apparatus allows for the platform to be locked outside its resting position by approximately 20 mm. The perturbation occurs when the fastening apparatus is released. The device was set to its easiest level with four unlocked springs.

The motion of the platform was recorded by using ultrasound transmitters and receiver (zebris CMS10 – zebris GmbH, Isny, Germany) at a measuring frequency of 100 Hz. The transmitters were rigidly attached to the platform. Data collection was done with WinPosture® software (zebris MedizinTechnik, Germany).The system recorded the platform position along the x and y axes and the yaw angle position along axis z where x is parallel to the perturbation, y is perpendicular to x and is in the horizontal plane and z is perpendicular to the horizontal plane pointing upwards. Position values were recorded at 0.1 mm resolution.

C. Measurement protocol

Participants were asked to stand barefoot in the middle of the measurement platform with arms hanging freely. Participants were allowed to shortly familiarize themselves with the unstable platform while listening to further instructions. A small number of unrecorded perturbation trials were also allowed to get participants accustomed to the procedure. Exclusion conditions that result in rejection of a recorded trial included touching the guardrails with any limb or shifting the position of the supporting feet. Participants were allowed up to 5 attempts standing on both legs, right leg and left leg to complete 3 successful balance regain using each stance.

D. Data processing

Processing of the recorded data was done using a custom LabView (National Instruments, Texas, USA) protocol. An example of the recorded position data is shown in Fig. 2. The noted and calculated parameters of the measurements were the following:

- Personal and stance identifier (one- or two-legged);
- End time of oscillation (in seconds);
- Lehr's ratio or damping factor (in percentage);
- Distance travelled parallel to perturbation (in millimetres);
- Distance travelled perpendicular to perturbation (in millimetres);
- Directional ratio.

DOI: 10.17667/riim.2017.1/1.

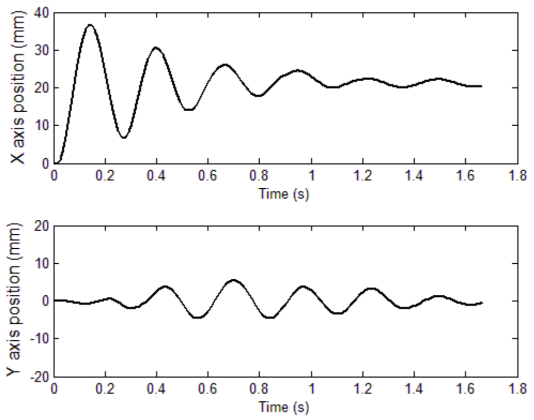

Fig. 2. Recorded data of platform position (example)

For the end time of balancing attempt, the final moment in time was considered when the oscillation of the platform stayed within a 2 mm range of the stationary position in all directions. For the calculation of Lehr's ratio the logarithmic decrement method was used accordingly to literature [14,19]. For distance travelled parallel to perturbation, the position time series along axis X was numerically differentiated to obtain velocity and the absolute value of velocity was integrated to obtain the length of path. The distance travelled perpendicular calculation featured position time series along axis Y and was calculated similarly. The directional ratio is the quotient of the distance travelled parallel and perpendicular to perturbation. For example, the motion trajectory of the balance regain attempt shown in Fig. 3 scores a directional ratio of 2.05, suggesting a prominent use of the antero-posterior direction.

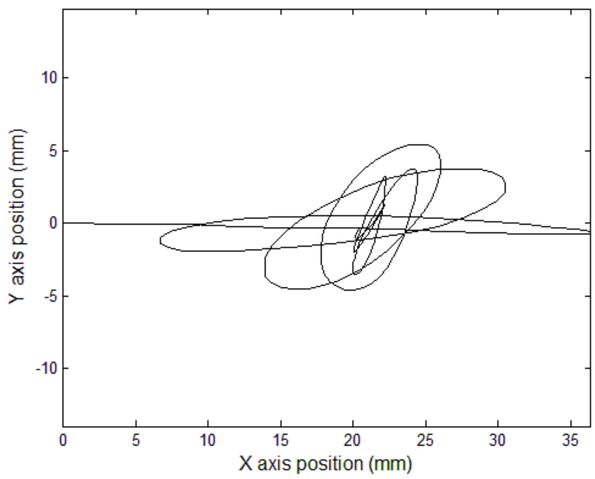

Fig. 3. Motion trajectory of a balance regain attempt (example)

Statistical methods were applied using Microsoft Excel's Analysis Toolpak® extension. Independent samples t-tests were applied to compare means of data sets; two tailed tests with significance level of α=0.05 were applied (*p value*). For correlation analyses, the bivariate Pearson correlation factor (*r value*) was used. 0.1 < |r|< 0.3 values were considered as weak, 0.3 < |r|< 0.5 values were considered as moderate, 0.5 < |r| values were considered as strong correlation.

III. Results

The overall numbers of successful recorded measurements were 71 in total; 42 one-legged and 29 two-legged stance balance regain were recorded. Numerical results are presented in Table 1.

TABLE I. NUMERICAL RESULTS

Skaters with two-legged stance					
n=29	***End time (s)***	***Lehr's ratio***	***Distance parallel (mm)***	***Distance perpendicular (mm)***	***Directional ratio***
mean	1.89	0.0624	189.5	50.7	4.12
SD	0.54	0.0171	51.3	20.0	1.40
Skaters with one-legged stance					
n=42	***End time (s)***	***Lehr's ratio***	***Distance parallel (mm)***	***Distance perpendicular (mm)***	***Directional ratio***
mean	2.52	0.0466	247.5	99.3	3.27
SD	0.83	0.022	86.9	64.4	1.77

TABLE II. PEARSON'S CORRELATION FACTORS (N=71)

correlation factors	***End time***	***Lehr's ratio***	***Distance parallel***	***Distance perpendicular***	***Directional ratio***
End time	1				
Lehr's ratio	-0.83	1.00			
Distance parallel	0.93	-0.84	1.00		
Distance perpendicular	0.49	-0.44	0.56	1.00	
Directional ratio	-0.05	0.07	-0.55	-0.71	1.00

TABLE III. RESULTS OF T-TESTS FOR ONE- AND TWO-LEGGED STANCES

Variables	***df***	***p (two-tailed)***	***p (one-tailed)***
End time	69	0.000	0.000
Lehr's ratio	68	0.001	0.000
Directional ratio	68	0.027	0.013

A. Correlations

Correlation analyses of data showed that the end time of balancing strongly correlates with Lehr's damping factor (r = -0.83) as presumed. This means that for performance evaluation

DOI: 10.17667/riim.2017.1/1.

purposes, these two values are interchangeable. However, the directional ratio showed weak or no correlation with Lehr's damping factor (r = 0.07) and the end time of balancing (r = -0.05). This suggests that the directional ratio contains new information about the balancing action.

B. Results of statistical analyses

Results for independent samples t-tests are shown in Table 3. One-legged stance results in significantly lower damping ($p < 0.00$) and longer end time ($p < 0.00$). The directional ratio of one-legged stance balance regain is significantly lower than of two-legged stances ($p = 0.013$).

IV. Discussion

The performance evaluation of dynamic balance regain test following a sudden perturbation is most convenient using the damping factor: a higher damping an athlete can exert on the oscillating system is associated with higher balancing abilities. An assumption is that balancing with a two-legged stance would yield superior performance to one-legged stances, even when standing on the dominant leg. In the current study it was not possible to determine the lateral dominance of participants. However, an earlier study found that there is no significant difference of balancing performance in a double stance to standing on the dominant leg [20]. The significantly lower value of directional ratio shows that achieving this high performance standing on a single leg might be made possible by adopting a more elliptical trajectory of motion.

V. Conclusion and Outlook

It had been well established that balance regain performance during perturbation tests can be characterized by the total time of the regain motion. The corresponding damping factor (Lehr's ratio) had also been used extensively in such studies. Now we introduced a promising a new variable, the directional ratio to characterize not the performance but rather the mode of balance regain. The weak correlation with previously used variables suggested new information content. Furthermore, we found that in the cases of one-legged stances the directional ratio is significantly lower than in two-legged stances. Determining the relationship between a less stable position and the directional ratio of the balance regain demands further research.

Recommended areas for future studies include studying the effects of age, gender, lateral dominance, athletic background (e.g. different sports) and health conditions on directional ratio of successful dynamic balance regain. We hope that different balance regain strategies can be characterized pairing Lehr's ratio with the damping ratio

References

[1] Winter, D. (2009). Biomechanics and motor control of human movement. Hoboken, N.J.: Wiley.

[2] Patla, A. (2003). Strategies for dynamic stability during adaptive human locomotion. IEEE Eng. Med. Biol. Mag., 22(2), pp.48-52.

[3] David A. Engström, J.A.Scott Kelso, Tom Holroyd (1996). Reaction-anticipation transitions in human perception-action patterns. Human Movement Science, 15(6), pp.809-832

[4] Rietdyk, S., Patla, A., Winter, D., Ishac, M. and Little, C. (1999). Balance recovery from medio-lateral perturbations of the upper body during standing. Journal of Biomechanics, 32(11), pp.1149-1158.

[5] Matjačić, Z., Voigt, M., Popović, D. and Sinkjær, T. (2001). Functional postural responses after perturbations in multiple directions in a standing man: a principle of decoupled control. Journal of Biomechanics, 34(2), pp.187-196.

[6] Giboin, L., Gruber, M. and Kramer, A. (2015). Task-specificity of balance training. Human Movement Science, 44, pp.22-31.

[7] Terry, K., Gade, V., Allen, J., F. Forrest, G., Barrance, P. and Thomas Edwards, W. (2011). Cross-correlations of center of mass and center of pressure displacements reveal multiple balance strategies in response to sinusoidal platform perturbations. Journal of Biomechanics, 44(11), pp.2066-2076.

[8] Schmid, M., Bottaro, A., Sozzi, S. and Schieppati, M. (2011). Adaptation to continuous perturbation of balance: Progressive reduction of postural muscle activity with invariant or increasing oscillations of the center of mass depending on perturbation frequency and vision conditions. Human Movement Science, 30(2), pp.262-278.

[9] http://www.bioswing.de/therapiesysteme/bioswing-posturomed/posturomed

[10] Müller, O., Günther, M., Krauβ, I. and Horstmann, T. (2004). Physikalische Charakterisierung des Therapiegerätes Posturomed als Meβgerät – Vorstellung eines Verfahrens zur Quantifizierung des Balancevermögens / Physical Characterization of the Therapeutic Device Posturomed as a Measuring Device – Presentation of a Procedure to Characterize Balancing Ability.Biomedizinische Technik/Biomedical Engineering, 49(3), pp.56-60.

[11] Orrell, A., Eves, F. and Masters, R. (2006). Implicit motor learning of a balancing task. Gait & Posture, 23(1), pp.9-16.

[12] Schmidt, D., Germano, A. and Milani, T. (2015). Aspects of Dynamic Balance Responses: Inter- and Intra-Day Reliability. PLOS ONE, 10(9), p.e0136551.

[13] Pfusterschmied, J., Stöggl, T., Buchecker, M., Lindinger, S., Wagner, H. and Müller, E. (2013). Effects of 4-week slackline training on lower limb joint motion and muscle activation. Journal of Science and Medicine in Sport, 16(6), pp.562-566.

[14] Kiss, R. (2011). A new parameter for characterizing balancing ability on an unstable oscillatory platform. Medical Engineering & Physics, 33(9), pp.1160-1166.

[15] Holnapy, G. and Kiss, R. (2013). Impact of the method of exposure in total hip arthroplasty on balancing ability in response to sudden unidirectional perturbation in the first six months of the postoperative period. Journal of Electromyography and Kinesiology, 23(3), pp.727-733.

[16] Kiss, R. (2012). Effect of degree of knee osteoarthritis on balancing capacity after sudden perturbation. Journal of Electromyography and Kinesiology, 22(4), pp.575-581.

[17] Pethes, Á., Bejek, Z. and Kiss, R. (2015). The effect of knee arthroplasty on balancing ability in response to sudden unidirectional perturbation in the early postoperative period. Journal of Electromyography and Kinesiology, 25(3), pp.508-514.

[18] Holnapy, G., Illyés, Á. and Kiss, R. (2013). Impact of the method of exposure in total hip arthroplasty on the variability of gait in the first 6months of the postoperative period. Journal of Electromyography and Kinesiology, 23(4), pp.966-976.

[19] Tweten, D., Ballard, Z. and Mann, B. (2014). Minimizing error in the logarithmic decrement method through uncertainty propagation. Journal of Sound and Vibration, 333(13), pp.2804-2811.

[20] Kiss, R. (2012). Biomechanikai módszerek a csípőízületi kopás hatásának vizsgálatára. MTA doktori értekezés. Budapest