COMPARATIVE RESTORATION OF BALANCE AFTER DISTURBING THE VESTIBULAR APARATUS WITH PASSIVE WHOLE-BODY ROTATION: CASE STUDY

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Abstract

The aim of this study was to establish whether the direction of the whole-body rotation influences the restoration of balance after the disturbance of vestibular apparatus with passive whole-body rotation. For this purpose, a chair powered by an electric motor was assembled. It rotates in a chosen direction for 10 seconds until it stops. It makes 11 turns in that time frame. The subject tested on the chair, is an active competitor of baton twirling. For baton twirling it is typical that the turns and pirouettes are performed in a counter clockwise direction (CCW). The results show that the direction of rotation influences the restoration of balance; the subject had better results in CCW rotation. COP (center of pressure) average in CW direction is 18.57% of time deviated to the left and 81.43% of time deviated to the right from center and in CCW direction is 53.83% of time deviated to the left and 46.17% of time deviated to the right from center in whole time of measurements. The differences in measurements depending on the direction of rotation and the deviation of the COP to the left and right of the center are significant.

Keywords*: biomechanics, balance, rotation, dominant side, baton twirling.*

INTRODUCTION

The maintenance of balance is a complex physiological process involving the interactions of numerous body sub-systems regarding the difficulty of the task and the environment. Neuromuscular and musculoskeletal components are important for the control of the body's position and motoric production. Sensory systems consisting of visual, vestibular and somatosensory components coordinate the information about the body's position relative to gravity and the environment and the position of body parts in relation to each other. Central nervous system processes (cognitive and non-cognitive) are also needed for adaptation and preventive aspects of balance control (Sihvonen, 2004).

We distinguish between stable equilibrium, labile equilibrium and indifferent equilibrium. Balance of the body is stable when the body weight returns to the initial position after a small shift from the starting point. Labile position of the body is an unstable state of the body; the body is thrown off balance by the slightest disturbance. Indifferent balance is balance that remains unchanged after a disturbance or returns to its original equilibrium position. Enoka (1994) says that the human body is in the upright and steady position, as long as the force vector of the central center of gravity remains within the boundaries of the base of support and remains stable, as long as it can adapt to interferences with the muscle-skeletal system and return to the state of equilibrium. “Because two-thirds of our body mass is located two-thirds of body height above the ground we are an inherently unstable system unless a control system is continuously acting”, says Winter (1995, p. 193).

Some authors (Tsigilis, Zachopoulou and Mavridis, 2001) do not only face the problem of measuring the balance and test reliability, but also the problem of defining balance. Balance should not be a general motoric ability, but highly specific capability, which depends on the performed tasks or the measurement test. Horak (1987, p. 1881) on the other hand defines balance as "the ability to maintain equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support."

To explore human body and balance in biomechanics, an inverted pendulum model is used. The ability to maintain a balanced position depends on the size of support surface, the center of gravity, height of the central body and its projections on the base of support (Winter, 1995).

In the upright position the base of support is determined by the position of feet including the area under and between the feet. More are the feet apart the greater is the base of support (Hochmuth, 1984).

The main factor in stable position is the strength angle which depends on the size of the support surface and the height of the center of gravity of the body. Strength angle is the angle between the force of gravity and the outer edge of the support surface (Marinšek, 2007).

Disturbances of the vestibular apparatus may be different. Activities such a walking, running, jumping, rotating and changes of the direction present a major challenge for balance system. These are the main movements in a variety of sport disciplines where the soft tissue of lower limbs is exposed to large dynamic forces (Emery, 2003).

Basic definitions

Posture. It describes the orientation of any body segment relative to the gravitational vector. It is an angular measure from the vertical (Winter, 1995).

Balance. Balance is a generic term describing the dynamics of body posture to prevent falling. It is related to the inertial forces acting on the body and the inertial characteristics of individual body segments (Winter, 1995).

Centre of mass (COM). It is a point, equivalent to a total body mass in the global reference system (GRS) and is the weighted average of the COM of all body segments in 3D space. It is a passive variable controlled by the balance control system. The vertical projection of the COM onto the ground is often called the center of gravity (COG). Unit of measurement of the COM is the meter (m) (Winter, 1995).

Centre of Pressure (COP). This is the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is totally independent of the COM. If one foot is on the ground the net COP lies within that foot. If both feet are in contact with the ground the net COP lies somewhere between the two feet, depending on the relative weight taken by each foot. Thus when both feet are in contact there are separate COP-s under each foot. When one force platform is used only the net COP is available. Two force platforms are required to quantify the COP changes within each foot. The location of the COP under each foot is a direct reflection the neural control of the ankle muscles. Increasing plantar flexor activity moves the COP anteriorly, increasing invertor activity moves it laterally. Its units are meters (m). In the literature there is a major misuse of the COP when it is referred to as sway, thereby inferring that it is the same as the COG (Winter, 1995).

When the COM of the body is positioned over the base of support (BOS) and aligned with the COP the equilibrium of vertical posture is achieved (Shumway-Cook and Woolacott, 1995; Winter, 1995). Base of support is the area within the system, which is in contact with the surface; its boundaries are defined by the maximum angle of deflection from the longitudinal axis, without the loss of the equilibrium position (O'Sullivan and Schmitz, 2001). Any body perturbation, either external such as a sudden translation of the support surface or internal such as fast arm or leg movement, shifts the projection of the COM closer to the borders of the BOS and the alignment between the COM and COP is disrupted: this may result in the loss of body equilibrium. To minimize the danger of losing equilibrium, the central nervous system (CNS) utilizes anticipatory postural adjustments (APAs) by activating the trunk and leg muscles prior to the forthcoming body perturbation. As a result of such anticipatory muscle activity, the observed displacements of the COM and COP are small (Belenkiy et al., 1967; Massion, 1992; Aruin & Latash, 1995; Li & Aruin, 2007 in Santos, Kanekar & Aruin, 2010).

When we have an internal or external balance disorder, balance is compensated by different solutions, depending on the degree of the disorder. Responses range from simple monosynaptic reflex to stretch, all the way to the activation of the balance strategies. Balance strategies are sensorimotor solutions which are used for maintenance of control over balance and include muscle synergists, movement patterns, torques in the joints and reaction base forces (Horak, Henry & Shumway-Cook, 1997).

When the projection COP does not cross borders of BOS when standing upright, the body uses two main strategies to compensate the loss of balance. When standing upright the stability can be maintained with ankles positioned front-to-back with the classic reflex of the stretch. The majority of the compensation movements are performed by the hock and foot (O'Sullivan & Schmitz, 2001; Winter, 1995). When the platform moves backwards, the gastrocnemii and hamstrings have the most common response with latencies of l00-120ms after the onset of platform translation. CNS first stabilizes the joint closer to the disturbance, in this case, the ankle, and then follows the stabilization of more distant joints - the knee, hip, and spine. Because the overall response begins in the ankle, such maintenance of the balanced position is called the "ankle strategy". (Balance is established by the invertors and evertors of the ankle.) (Winter, 1995). When it comes to the balance disturbances in the left-right direction (latero-medial disruption), the body responds with a "hip strategy"; a more complex movement, particularly in hips and torso (Winter, 1995), Thus the body enables the activation of major muscle groups, which are easier to withstand unexpected movements (O'Sullivan & Schmitz, 2001). The hip strategy therefore prevails when the muscles around the ankle cannot provide sufficient corrective torque to keep the COM within the BOS, which is typical of larger and faster disruptions of COM (Winter, 1995; Horak, 1987).

For maintaining balance and body posture we have the so-called control system consisting of a sensory system for detecting movement of the body segments, central nervous system (CNS) for processing data and motor system which performs motor tasks (Horak, Nasher and Diener, 1990; Shumway-Cook & Horak, 1986, in Omejec, 2007). The ability to maintain balanced position is based on very complex connections between vision, sensorimotor system, vestibular apparatus and coordination of movements with muscle activity (Horak, 1987). When subjects change the sensory environment, they need to re-weight their relative dependence on each of the senses. In a well-lit environment with a firm base of support, healthy persons rely on somatosensory (70%), vision (10%) and vestibular (20%) information (Peterka, 2002).

Although vestibular sensation is less prominent than that for the senses, the vestibular apparatus signals are essential for the maintenance of body posture and the generation of movement. Vestibular signals help stabilize the head, which, since it houses all of the spatial sense organs, must be kept focus on objects of interest. In addition, if the head moves, the vestibular signals can move eyes within the head, in order to change the direction of view and aim the retina. Finally, vestibular signals cause the convenient synergistic action of legs and trunk muscles to provide a stable body platform from which the eyes and head movements can be initiated (Fuchs, 1989).

Vestibular organ in bony structure of the inner ear in association with the auditory organ, the cochlea and they form two functional units. The two otolth organs sense linear acceleration and its gravity, and the three semicircular canals sense rotational movement in space and detect angular accelerations. With the two organs oriented at right angles to each other, the direction of linear acceleration is spatially encoded in three dimensions and the magnitude of the acceleration is encoded by the firing rate. As the head rotates, the inertial force of the fluid in the semicircular canals deflects the cilia of hair cells aligned with the canals, modulating the firing of the afferent nerves. With the three semicircular canals aligned at right angles to each other, rotation in any direction can be resolved. (Day and Fitzpatrick, 2005). The vestibular nerve then transmits sensory impulses from the semi-circular canals into the cerebellum, which, together with the information from the eyes and joints take care of the balance (Smith, 1992).

Relatively selective stimulation of the horizontal semicircular canals can be applied to a subject who seated in a rotational chair with their head fixed at a 30° angle below the horizontal plane. At the onset of rotation, the inertia of the endolymph fluid in the horizontal canals bends the hair cells (the canal receptors) in a direction opposite to that of head rotation. When the chair is stopped suddenly, the same inertial force will continue to bend the hair cells, this time in the same direction of head rotation even though there is no longer any head rotation. If subjects are made to stand with eyes closed, then they have to suppress these erroneous vestibular inputs and rely on correct somatosensory inputs to maintain standing balance (Horak, Shupert & Mirka, 1989, in Tsang & Hui-Chan, 2006).

The following research (Tsigilis, Douda, Mertzanidou & Sofiadis, 1998) investigated and compared the difference in balance stability of 12 rhythmic gymnast and 17 basketball players after the vestibular apparatus stimulation. All the subjects were female, aged from 9 to 11. The stimulation of vestibular apparatus (semicircular canals) was achieved by a rotation chair (Barany's chair). The chair was programmed to make 10 rotations in 20 seconds. For measuring the static balance they used the Flamingo test and for measuring the dynamic balance the subjects had to walk in a straight line. The subjects had done the balance tests before and after the rotations with »Barany chair«. The analysis of results had shown that gymnasts had better balance stability than basketball players both before and after rotation. They concluded that the main difference was training. Gymnasts have different motor experience, because their training is composed of various repetitions of rotations and pirouettes in frontal and sagittal plane. That improves the efficiency of their vestibular apparatus. The basketball players lack such training. The authors concluded that specific training influences the adaptation of vestibular apparatus to a large extent. Despite better results of the gymnasts, it does not mean they are better in motor control, (but they certainly have the predisposition in establishing and maintaining balanced position.)

Starosta (1986) did an analysis of the direction of rotation on vertical axis. The direction of turns made by 6701 child and adult athletes in 4 sports (figure ice-skating, roller skating, gymnastics, kayaking) was analyzed. The results showed that turn direction varies with type of sport, gender, complexity of exercise, and handedness.

Interestingly, individual preference for the direction of turn might strongly influence on the dancer's skills in performing whole body rotation. For adult classical ballet dancers a rightward turning bias has been described, while the untrained controls predominantly showed a leftward turning bias and a weaker dependence between the direction of rotation and leg preference than dancers (Golomer, Rosey, Dizac, Mertz & Fagard, 2009).

In the research (Čuk and Marinšek, 2013) the aim was to determine which biomechanical characteristics of landing best predict the quality of landing. Twelve male gymnasts performed a stretched forward and backward salto; also with 1/2, 1/1 and 3/2 turns. Stepwise multiple regression extracted five predictors which explained 51.5% of landing quality variance. All predictors were defining asymmetries between legs (velocities, angles). To avoid asymmetric landings, gymnasts need to develop enough height; they need higher angular momentum around the transverse and longitudinal axis and they need to control better the angular velocity in the longitudinal axis.

The aim of the research is to establish whether the direction of rotation has any influence on restoring balance after disturbing the vestibular apparatus with whole-body rotation.

METHODS

In this study the subject was an active baton twirling competitor. Baton twirling is a poly-structural conventional sport, including aesthetic and choreographically placed acyclic motion structures with a baton. It combines the skillful mastery of baton manipulation, body movement, dance and gymnastics utilizing an array of musical selections (WBTF Coach Manual, 2007). Moreover it has similar movement patterns and prop work as rhythmic gymnastics. For baton twirling it is typical that when the baton is released in the air (aerial) the competitor makes multi successive turns of the body, usually towards the left on the left foot, and then catches the baton. Measurements were made in biomechanics laboratory at the Faculty of Sport in Ljubljana and were made according to Helsinki declaration.

For the constancy of the measurements a rotating chair powered by 100W electric motor was made. The motor was programmed to rotate for 10 sec, and then automatically stop. The chair makes 11 rotations until it stops. The chair has a back rest to ensure the same position of the subject throughout the test. The subject was sitting on the chair during the rotation and when it stopped the subject stood up and stepped to the force platform where she stood still for 30 seconds. The subject was standing narrow astride, heels were approx. 2 cm apart, and hands were akimbo, looking forward (Fig. 1.). We were interested in the foot, with which the subject stepped on the force platform.

Figure 1. *The position of the subject on the force platform.*

With force platform the oscillation of the body was measured for 30 seconds with frequency of 100 Hz, as to acquire value AP (anterior-posterior) (m) and ML (medial-lateral) (m) components of COP (Centre of pressure) and with this also the path of COP.

Measurements have been repeated 12 times in CW direction and 12 times in CCW direction. Between the tests there was 1 min of delay for the subject to rest and to stabilize the vestibular system. 3 measurements in succession have been done for each direction. Between any of series it was 3 min delay for change the direction of electric current and with this also the direction of chair's (motor's) rotations.

The results have been analyzed in Excel 2010. The data of body sway in medio-lateral and anterio-posterior have been arranged increasingly and the time when COP moved in one or other side respectively anterior or posterior have been compared. Statistics have been made in program IBM SPSS Statistics 20.

T tests have been made separate for ML and AP namely between sway medio/lateral respectively antero/posterior for CW in CCW in first 10 sec and in whole time of measurements (30 sec). With T test for independent sample the differences between sways for CW in right and CCW in left for 10 in 30 sec. and also differences between sways CW forward and CCW forward for 10 in 30 sec. have been compared.

RESULTS

If we rotate in CW direction, it is aspect that when we stand, in time of vestibular stabilization after rotation, we are still sway forward and in right because of disturbance of vestibular apparatus and the felling of rotation, which is still present. Inversely valid for rotation in CCW direction, we should be sway forward and to the left. Because of this in research the time when COP was the sway lateral from center and the sway medial from center have been compared.

The average, standard deviation and standard error for the percent of time deviation COP to the left or right from center after rotation in CW direction and CCW direction, divided by time (10 sec, 30 sec), is presented in Table 1 and Table 2. In first 10 seconds after rotation in CW direction is COP average 27.25% of time deviated to the left and 72.75% of time deviated to the right from center. In whole time of measurements (30 sec) is COP 18.57% of time deviated to the left and 81.43% of time deviated to the right from center. Data presents quite difference in deviation at one or the other side from center.

After rotation in CCW direction in first 10 sec the COP average is 43.40% of time deviated to the left and 56.60% of time deviated to the right from center. In whole time of measurements is COP averagely 53.83% of time deviated to the left and 46.17% of time deviated to the right from center, what indicates a smaller difference than the rotation in CW direction.

T test (paired) between deviation COP to the right and deviation COP to the left from center for first 10 sec after rotation in CW direction presents statistically significant differences between groups, they are also statistically significant differences for the entire measurement time, while the non-significant difference are for the rotation in CCW direction as for 10 seconds, as well as for the entire measurement.

Table 1. *Percent of time, while the COP is deviated medial and lateral, after the rotation in CW direction.*

time (%) Measure	10 seconds		30 seconds	
	left dev.	right dev.	left dev.	right dev.
average	27.25	72.75	18.57	81.43
St. dev.	25.26	25.26	25.40	25.40
St. err.	7.29	7.29	7.33	7.33
p (t-test)	.000†		.000 ‡	

Notes: p< .05, two tailed paired; † deviation to the left - deviation to the right, 10 sec; ‡ deviation to the left - deviation to the right, 30 sec

Table 2. *Percent of time, while the COP is deviated medial and lateral, after the rotation in CCW direction.*

Measure	time (%) 10 seconds			30 seconds
	left dev.	right dev.	left dev.	right dev.
Average	43.40	56.60	53.83	46.17
St. dev.	25.48	25.48	32.35	32.35
St. err.	7.36	7.36	9.34	9.34
p (t-test)	.218†		.568‡	

Notes: p< .05, two tailed paired; † deviation to the left - deviation to the right, 10 sec; ‡ deviation to the left - deviation to the right, 30 sec

Table 3. *Comparison of the results after rotation in CW and CCW direction.*

	M	p (t-test)	Df
CW, deviation to the right, 10 sec	72.75	.001**	22
CCW, deviation to the left, 10 sec	30.99		
CW, deviation to the right, 30 sec	81.43	.030**	22
CCW, deviation to the left, 30 sec	53.82		

*Notes:**p< .05, two-sample equal variance*

Table 3 shows that is with the T-test for independent samples (two-sample, equal variance) between the rotation in CW and CCW direction confirmed that both, the first 10 seconds, as well as the whole of the measurement, the difference between the groups are statistically significant (p = .001; p = .030).

It doesn't matter in which direction we are rotating in, we have the feeling like we are always going forward. That's why COP is expected to be deviated a bit anterior from center, whatever way we're rotating in. Averages of both directions (CW and CCW) were made separately. Results are showing that after any rotation (CW and CCW direction) there aren't main differences between deviation anterior or posterior. The most noticeable differences can be noticed in first 10 seconds after rotation in CCW direction, where deviation posterior averagely lasts 31.55% while anterior 68.45%. T test (paired) between deviation of COP anterior and posterior separately for the first 10 seconds and 30 seconds, did not point out any statistical differences. We can also notice, that the T test for independent samples (two-sample equal variance), where we were comparing results after both rotations, did not show any statistically significant differences.

Graphical display shows average path of deviation to medial or lateral after rotation in CW and CCW direction (Fig. 2). The difference between results after rotation in CW and CCW direction is very clearly shown. After rotation in CW direction, deviation starts on left side and goes towards right side, while after rotation in CCW direction deviation starts on right side and goes towards left side. After rotation in CW direction, slightly bigger deviation of COP towards right direction can be seen. After rotation in CCW direction deviation is equally distributed around the center. Balance is sooner and better achieved, when subject is rotating in CCW direction. There aren't any significant differences in anterior and posterior direction, according to rotation before (Fig. 3.). It seems that both average paths of COP are traveling in the same direction. Although, after rotation in CCW direction is COP during 4^{th} and 18^{th} second slightly deviated anterior. That differs from results after rotation in CW direction, when COP is close around center. After 19^{th} second path of COP, after rotation in CCW direction, narrows to the center, while average path COP after rotation in CW direction deviates a bit posterior. As predicted, deviation of COP is irrelevant to the course of rotation and deviated anterior.

After test subject has rotated in CW direction, the biggest deviation has been noted in the medial-lateral to the left side (left = -.036;right = .030). After rotation in CCW direction, the biggest deviation has been noted to the right side (right = .044; left = -.027). In anterior-posterior direction has been at the beginning in both cases the COP path deviated anterior and so was the biggest measurement (CW: anterior = .048,posterior = -.028; CCW: anterior = .045, posterior = -0.033).

On the 4^{th} graph (Fig. 4.) average path COP of all of the measurements, separated for after rotation in CW and CCW direction, has been drawn. The average COP path after rotation in CW direction starts on the left side and travels towards right side. That can be clearly seen on the graph. One can also notice that the average path COP after rotation in CCW direction starts on the right side and goes towards left side. On the 4^{th} graph, there is also noticeable, that the average path COP after rotation in CW direction stabilize a bit further to the right side in comparison to the average path COP after rotation in CCW direction, where COP path in arranged mostly equally around the center, but it is still deviated a bit anterior in comparison to the average COP path after rotation in CW direction.

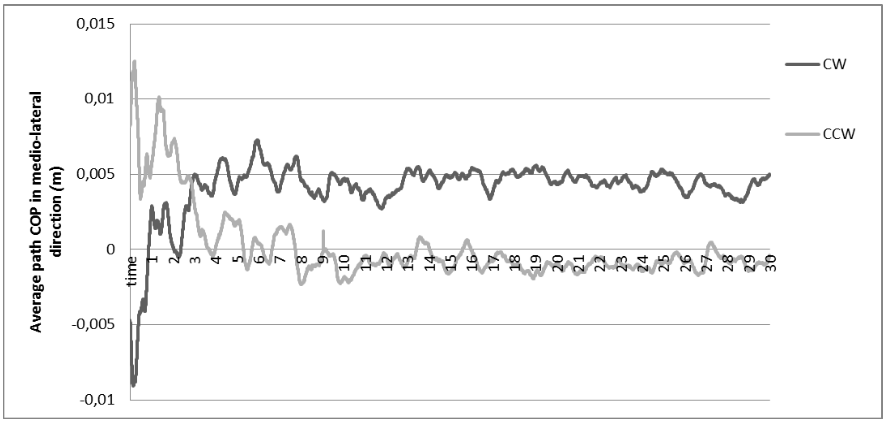

Figure 2. *Average path COP in medio-lateral direction.*

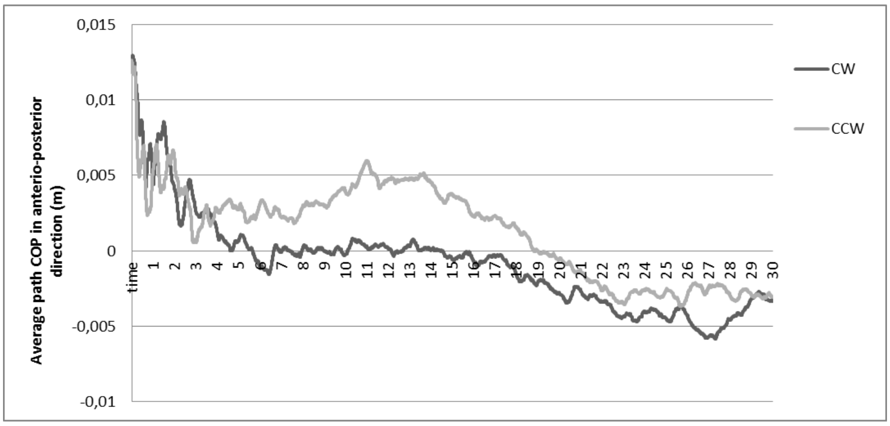

Figure 3. *Average path COP in anterior-posterior direction.*

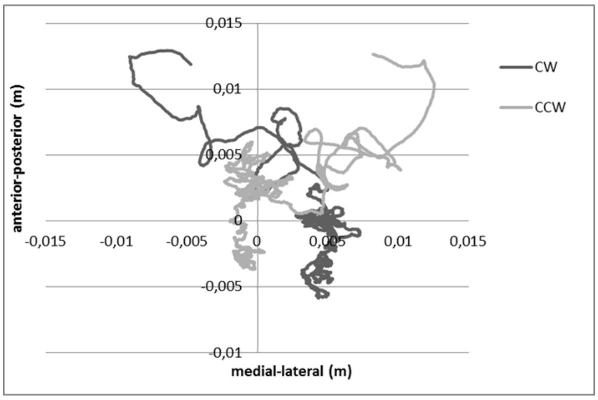

Figure 4. Path *COP after rotation in CW and CCW direction.*

DISCUSION

In this study we observed whether human body responds differently to vestibular system disturbance with passive whole-body rotation relative to the direction in which it rotates. From the previous studies, we can conclude that people consciously mostly rotate in a CCW direction, but people who have trained sport where there are rotations to the CW (dance, rhythmic gymnastics) for years, rotate in a CW direction.

In our case, the tested subject was a baton twirling competitor, which mainly rotates to the CCW direction on the left foot. The subject was expected to be able to better maintain balance after the whole-body rotation in a CCW direction, then after the opposite direction.

For the analysis the data of COP deviation from the center in lateral-medial and anterior-posterior direction has been used. The data of COP measurements after rotation in a CW and after rotation in the CCW direction has been compared.

Comparison between the time when the COP is deviated to the left and when it is deviated to the right from center shows that after the rotation in CW direction the average of time when the COP is deviated to the left is 27.25% and the average of time when the COP is deviated to the right is 72.75%, in the overall measurement. During first ten seconds of measurements average of time when the COP is deviated to the left is 18.57%, and when the COP is deviated to the right is 81.43% of time. After rotation in CCW direction the differences were smaller. Namely the average time of the COP being deviated in left direction from the center has been 43.40% and the average time of the COP being deviated in right direction from the center has been 56.60% as noted during all of the measurements. During the first 10 seconds the COP average of time deviated to the left from center was 53.83% and the 46.17% of time deviated to the right. Also, the graph shows that the stabilization of the balance after the rotation in the CCW direction was better than in the CW direction.

T-test (paired) has been made between COP deviation to the right and left from center during the first ten and thirty seconds after rotation in CW and CCW direction. With the 5% certainly we can confirm that there are typical statistical differences after rotation in CW direction in the first 10 seconds of the COP deviation from the center between left and right ($p = .000$). Even in the 30 seconds of measurements there were statistical differences between the COP deviation from the center ($p = .000$). After rotation in CCW direction, there were no statistical differences (10s: $p = .218$; 30s: $p = .568$).

The T-test for independent samples (two-sample equal variance) has also been done, where we were ascertaining the differences between the deviations of the COP from the center after rotation in CW and CCW direction. The results shows that with 5% of certainty there are significant statistical differences between the groups (10s: $p = .001$; 30s: $p = .030$).

An analysis has also been made in the anterior-posterior direction. The average deviation in the anterior direction of the COP during the first 10 seconds after rotation in CW direction was 57.93% of time, and 42.07% of time in posterior direction. In the whole measurement the average of COP deviation from the center was 57.70% of time in the anterior direction and 42.30% of time in the posterior direction. After rotation in CCW direction during the first 10 seconds the deviation in anterior direction from center was 68.45% of time and 31.55% of the time in posterior direction from center. During the whole 30 seconds the average is 54.76% of time when deviation was in anterior direction from center and 45.24% of time when it was in posterior direction from center.

The T-test (paired) between the groups has shown no statistical differences (CW, 10 s: $p = .480$; 30 s: $p = .484$; CCW, 10 s: $p = .094$; 30 s: $p = .625$). Also the T-test for independent samples (two-sample equal variance) between the results after the measurement in the CW direction and after CCW direction the difference is not statistically significant (10 s: $p = .235$; 30 s: $p = .318$).

The graphical presentation of the average path of the COP for measurements after CW direction and after CCW direction shows, that in general path COP of the rotation in the direction of CW starts on the left side and moves to the right. On the contrary, the average path COP of the rotation in the direction CCW starts at the right side and moves to the left, as has also been provided.

The differences can be explained as a consequence of rotation in either direction. During first seconds after the rotation the vestibular system is still disturbed. Inertia of endolymph fluid in horizontal half-circle canals bends their hair in the opposite direction of heads movement, although when one's head stops moving, that fluid doesn't stop spinning at the moment, and that inertia force keeps bending hair inside canals, and that makes one feel like one's still rotating. This could be a reason for the displacement of the COP in direction of whole-body rotation.

The research has also concluded that there are the differences of establishing the balance after the rotation in one or the other side and that the subject better established a balance after rotation in CCW direction than after rotation in CW direction. The differences are particularly noticeable at deviation of COP from the center towards medial or lateral while anterior and posterior, there was no significant difference.

The reason for the difference in measurements is usually reliable of subject's preparedness or training because the subject is actively practicing baton twirling where they mainly rotate in CCW direction.

Finally, the study found that training effects on response of vestibular system and the establishment of equilibrium. However, trainers should have prepared the athletes also for rotation in non-dominant direction of rotation in a particular sport. It can happen that the competitor should have made an element which requires rotation in non-dominant side, but won't be able to make it because of over-trained dominant side.

Probably long-term asymmetric burdening can cause acute (mostly like ankles or knees) or chronic injuries (most likely the back trunk) (Steffen, Baramki, Rubin, Antoniou and Aebi, 1998; Yeadon, 1999 in Čuk and Marinšek, 2013). It is also possible that there would be a deformation of the physical characteristics and thus collapsed posture, which would again lead to injury. In competitive sports have over-trained dominant direction of rotation may also have implications in the implementation of elements. It might happen that the competitor will be forced to perform an element that has a rotation in the opposite direction, as usually done, or will be due to an error in the composition the next element should continue differently (the other way), for which will need a sense of rotation of the both directions.

The results of the pilot study provide us with a good starting point for further research on more people. It would be good to extend research with a focus on dominance and asymmetry of the body.

Beside this it could be very interesting to compare two kinds of athletes. Athletes in significant asymmetric sports like basketball, football, ninepins and the other in significant symmetric sports like track and field (running), swimming, gymnastic, skiing. With this test we can find out if the asymmetry of the body may influence the body stabilization.

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