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The role of lateral preference of lower limbs in a postural stabilization task

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Abstract

OBJECTIVE: Postural control is a complex skill based on the interaction of dynamic sensorimotor processes. This study assessed the effect of lateral perturbations on postural re-stabilization regarding lower limb preference.
METHODS: A group of 14 physically active individuals (9 male, 5 female) randomly underwent postural perturbations in lateral-left and lateral-right directions at a velocity of 0.2 $m.s^{-1}$ and a platform shift of 6 cm. Perturbation to the preferred limb side (PS) was noted when the contralateral body movement was primarily controlled by the preferred limb and perturbation to the non-preferred limb side (NS) was noted when the contralateral body movement was primarily controlled by the non-preferred (stabilizing) limb. Prior to, during and after the perturbation centre of pressure (CoP) was registered using a computerized motor driven FiTRO Dynamic Posturography System based on force plate (Fitro Sway Check) with a sampling rate of 100 Hz. The basic stabilographic parameters of peak displacement (Peak 1), peak-to-peak displacement (Peak 2), time to peak displacement (Time 1), time to peak-to-peak displacement (Time 2) and re-stabilization time (Time 3) were analyzed.
RESULTS: Results showed significantly larger Time 3 on PS than on NS (2.81±1.32 s and 1.73±1.10 s; p=0.02). However, there were no significant differences in other parameters between PS and NS.
CONCLUSION: It may be concluded that the observed shorter re-stabilization time at NS was due to the stabilization role of the non-preferred limb.

ORIGINAL ARTICLE

INTRODUCTION

The ability to stand and to walk in a safe manner depends on a complex interaction of physiological mechanisms (Horak 2006). Multiple levels of hierarchical feedback contribute to posture control; the balance is continuously stabilized through the integration of visual, vestibular, proprioceptive, and other sensory inputs (O'Connor & Kuo 2009). The postural control can be influence also by the time of day ((Mokošáková *et al.* 2014). In many sports athletes work in "unstable" environments and control their dynamic posture in unexpected situations. Most perturbations in the form of rapid changes of positions or contacts are performed laterally or from the lateral side. Medial-lateral postural control is dominated by the limb loading/unloading mechanism (Rietdyk *et al.* 1999; Winter *et al.* 1996). However, there are scarce reports about this mechanism in relation to lower limb laterality. Some authors use the term "dominant limb" to describe the leg that is used for mobility or manipulation of an object (Hoffman *et al.* 1998; Matsuda *et al.* 2008), while others use the term "preferred limb" (Teixeira *et al.* 2011; Carpes *et al.* 2010). In such a bilateral context, the consensus is that the mobilizing limb is the preferred (dominant) limb, whereas the limb that is used to support and stabilize the actions of the preferred limb is considered the "non-preferred (non-dominant) limb" (Gabbard & Hart 1996). Sadeghi *et al.* (2000) consider laterality as an another explanation for the observed functional differences between lower limbs and also as more general term to express the existence of limb dominance. The influence of lateral preference on postural stability in athletes and healthy individuals has previously been primarily related to the static single leg stance (Niu *et al.* 2012; Matsuda *et al.* 2008; Hoffman *et al.* 1998), or to dynamic conditions in the form of single-leg landing (Ross *et al.* 2005; Wikstrom *et al.* 2006). However, unilateral tasks, such as the one-leg stance, are questionable because they do not provide clear bilateral role differentiation (Gabbard & Hart 1996).

Sudden perturbations applied to the body during competition can potentially move the centre of gravity outside the base of support and avoid losing balance and falling. The displacement of the centre of pressure (CoP) and its re-stabilization can be used as a measurement tool of stabilizing reactions in unexpected perturbations (VanMeter 2007; Yoshitomi *et al.* 2006; Zemková *et al.* 2005). Rapid readjustment of balance after perturbation to baseline is considered an important ability in sports, but it also depends on perturbation velocity (Diener *et al.* 1984). In previous studies (Hughes *et al.* 1995; Hwang *et al.* 2009; Runge *et al.* 1999), authors used velocities in the range of 0.05 to 0.55 $m.s^{-1}$. These were suitable to induce postural imbalances in patients and also in the elderly. On the other hand, we did not found reports related to the effect on postural control in physically active individuals.

Time to stabilization as a method used for analyzing dynamic postural stability has been primarily related to measuring functional ankle instability (Brown *et al.* 2004; Ross & Guskiewicz 2004) and to ACL impairments (Colby *et al.* 1999; Webster & Gribble 2010). However, there are no known studies which assess the effect of lower limb laterality and the asymmetrical behavior of lower limbs during stabilization tasks after lateral perturbations in healthy physically active individuals. Body reaction after impacts significantly influences movement kinematics (Fanta *et al.* 2013). Therefore this study evaluates the effect of unexpected lateral perturbations on postural re-stabilization regarding lower limb preference in physically active individuals. It can be hypothesized that the body perturbation primarily controlled by the non-preferred lower limb will be associated with lower re-stabilization time rather than body perturbation primarily controlled by the preferred limb.

METHODS

Subjects

Fourteen fit young individuals (9 male, age 23.2 ± 3.3 y; height 177.4 ± 3.2 cm; weight 77.9 ± 7.1 kg and 5 female, age 25.0 ± 4.0 y; height 167.8 ± 5.4 cm; weight 59.8 ± 5.6 kg), volunteered to participate in this study. All participants were healthy and void of diseases known to affect the neuromuscular control mechanisms underlying balance. They were informed about the purpose of the study and potential risks. The study was approved by the Institutional Research Ethics Committee and was performed in accordance with the Ethical Standards on Human Experimentation as outlined in the Declaration of Helsinki.

Experimental protocol

Firstly, the group was assessed for lower limb preference through the three following tests: the ball kick test, the step-up test and the balance recovery test. In the ball kick test, the subjects were asked to kick a ball placed in front of them with maximum accuracy through a goal. The step-up test required the subject to step onto a 20-cm high step. In the balance recovery test, subjects were nudged off-balance from behind by the tester. The leg that was used to kick a ball, step onto a step and step out to regain balance was considered as preferred. From each test, three trials were obtained. The leg that was used to perform the task in the most trials was considered as functionally preferred.

Prior to the perturbation, five seconds of quiet stance was recorded. The centre of pressure (CoP) was registered by using a FiTRO Sway Check System (FiTRONIC, Bratislava, Slovakia) based on force plate with a sampling rate of 100 Hz. The stable range in which mean CoP excursion occurred was used as a baseline for determination of the re-stabilization. Following this, participants underwent, in random order, two attempts of postural perturbations in a lateral direction (lateral-left and lateral-right, respectively) at a velocity of 0.2 m.s^{-1} and a platform shift of 6 cm. To avoid learning effect, they were not informed about the upcoming perturbation's direction and velocity. Perturbation to the preferred limb side (PS) was noted when the contralateral body movement was primarily controlled by the preferred limb; perturbation to the non-preferred limb side (NS) was identified when the contralateral body movement was primarily controlled by the non-preferred (stabilizing) limb. A computerized motor driven FiTRO Dynamic Posturography System (FiTRONIC, Bratislava, Slovakia) was used to monitor basic stabilographic parameters such as peak displacement (Peak 1), peak-to-peak displacement (Peak 2), time to peak displacement (Time 1), time to peak-to-peak displacement (Time 2), and re-stabilization time (Time 3) (Figure 1). The total duration of the re-stabilization phase was 5.0 s and as onset was considered Peak 2. The CoP location (in each 0.01 s) was tracked as it oscillated after the perturbation, with all subjects following a regular damped oscillation. When that oscillation decreased in magnitude and appeared stable or at about the previous baseline level, the re-stabilization time was established. One deflection from the set interval was allowed.

Data analysis

Statistical analysis was performed using Statistica software (version 10, StatSoft, Inc., Tulsa, OK). The normal distribution of data was confirmed by the Kolmogorov-Smirnov test. Student's t test was used to investigate the differences between variables, and statistical significance was accepted at $p<0.05$. The average of two trials was analyzed. Pearson's correlation analysis was performed between the CoP variables. Significance level was set at $p<0.05$. According to Cohen (1988), the effect size was calculated and interpreted as follows: large effect $d>0.8$, medium effect $0.5<d<0.8$, small effect $d<0.5$.

RESULTS

The values are presented as a mean (standard deviation) for both perturbation sides in Table 1.

The re-stabilization time differs significantly between lower limbs (Figure 2). Shorter re-stabilization time was found on the perturbation side primarily controlled by the non-preferred limb (stabilizing) than on the side primarily controlled by the preferred limb (38.4%, $p=0.02$). This was corroborated also by large effect size ($d>0.8$). However, there were no significant differences in Peak 1 (1.7%), Peak 2 (4.7%), Time 1 (1.5%) and Time 2 (6.9%), between perturbation sides.

Pearson's correlation analysis revealed a significant relationship for several parameters (Table 2). For both perturbation sides, there was significant ($p=0.03$; $p=0.01$) negative relationship between peak-to-peak displacement (Peak 2) and time to peak-to-peak displacement (Time 2).

Regarding lower limb laterality, significant ($p=0.01$) negative correlations between peak-to-peak displacement (Peak 2) and re-stabilization time (Time 3) was found when the body perturbation was primarily controlled by the preferred limb. Similarly, there was a

Tab. 1. The CoP variables between preferred and non-preferred limb side.

Variable	PS mean (SD)	NS mean (SD)	p-value	Cohen's d
Peak displacement (cm)	10.90 (1.68)	11.09 (1.89)	0.79	0.11
Peak-to-peak displacement (cm)	15.37 (3.91)	16.13 (4.98)	0.35	0.17
Time to peak displacement (s)	0.38 (0.05)	0.39 (0.03)	0.67	0.14
Time to peak-to-peak displacement (s)	0.37 (0.08)	0.39 (0.10)	0.16	0.29
Re-stabilization time (s)	2.81 (1.32)	1.73 (1.05)	0.02	0.9

PS – perturbation to the preferred limb side, NS – perturbation to the non-preferred limb side.

Tab. 2. Results of Pearson correlation analysis for variables on preferred and non-preferred limb side.

	Time 1		Time 2		Time 3		Peak 1	
	PS	NS	PS	NS	PS	NS	PS	NS
Time 1								
Time 2	−0.20	0.42						
Time 3	0.10	−0.40	0.35	−0.02				
Peak 1	−0.03	−0.40	−0.52	−0.17	−0.37	0.74***		
Peak 2	−0.24	−0.03	−0.59*	−0.64**	−0.68**	0.04	0.80**	0.33

PS – perturbation to the preferred limb side, NS – perturbation to the non-preferred limb side. Peak 1 – onset of perturbation to peak displacement, Peak 2 – peak-to-peak displacement, Time 1 – time to peak displacement, Time 2 – time to peak-to-peak displacement, Time 3 – re-stabilization time. *$p<0.05$, **$p<0.01$, ***$p<0.001$

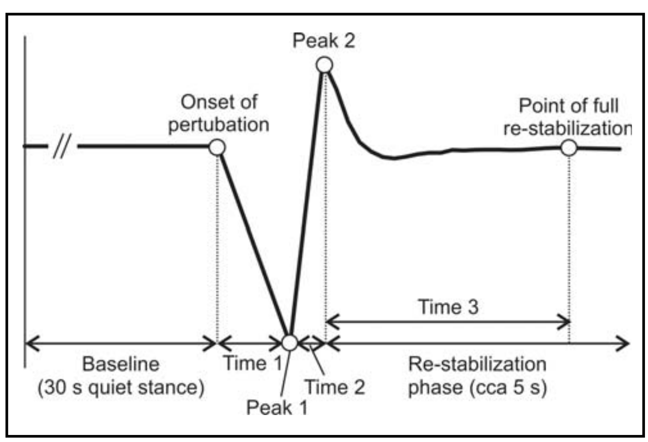

Fig. 1. Basic stabilographic parameters.

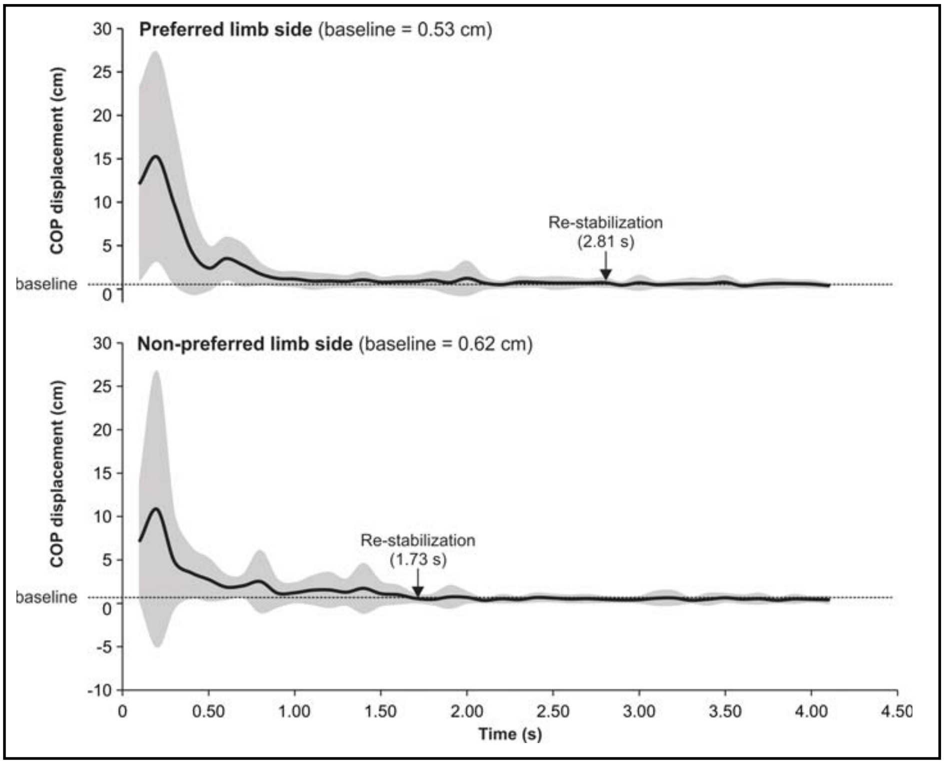

Fig. 2. Differences in re-stabilization time between limbs. The thick black line indicates the mean value and the shaded area corresponds to one standard deviation about the mean.

significant ($p<0.01$) positive relationship between peak displacement (Peak 1) and peak-to-peak displacement (Peak 2).

When the body perturbation was primarily controlled by the non-preferred (stabilizing) limb, significant ($p<0.01$) positive correlation was found between peak displacement (Peak 1) and re-stabilization time (Time 3).

DISCUSSION

The control of posture consists of sensory systems, the motor system, and the control system, which involves complex interactions among multiple neural systems (Horak & MacPherson 1996).

This study evaluated the postural re-stabilization after unexpected lateral perturbations regarding lower limb preference in physically active individuals. A shorter re-stabilization time was found on the perturbation side primarily controlled by the non-preferred (stabilizing) limb in comparison to the side primarily controlled by the preferred limb. This was corroborated also by large effect size. Despite larger, but insignificant, CoP displacements (Peak 1 and Peak 2) and longer times (Time 1 and Time 2), participants were able to re-stabilize their postures more quickly than in perturbations primarily controlled by the preferred limb. These findings could support the idea of existing laterality in stabilization tasks where the non-dominant limb has a stabilizing function and produces the majority of the control during the performance (Carey *et al.* 2001; Connor 2013; Rahnama *et al.* 2005). However, Ross *et al.* (2004) found no significant differences in time to stabilize posture after single-leg landing between dominant (kicking) and stance limb. As was mentioned, this test met the requirement for including sports-related function, but it is difficult to obtain reliable measurements because is difficult to standardize and introduces considerable variability into the testing protocol in terms of jump height and various landing techniques (Ross *et al.* 2005). Moreover, we consider single jump landing as an expected and self-induced form of perturbation, while in sports performance posture is mainly controlled during unexpected situations induced by an opponent.

The difference in re-stabilization time between sides was 1.076 seconds with shorter re-stabilization on the non-preferred limb side. This side-to-side difference could negatively affect the performance, predominantly in sports with a rapid succession of actions within a short period of time, such as combat sports. For example, a roundhouse kick in Taekwondo – according to height and distance – takes from 0.461 to 0.675 seconds (Estevan & Falco 2013). This means that sudden perturbations in the form of two kicks applied to the body during re-stabilization on the preferred limb side can potentially negatively affect the athlete's balance during different bilateral weight-bearing tasks. This may result in losing balance and falling, which can ultimately lead to the loss of a match.

Re-stabilization time on the preferred limb side significantly negative correlated with peak-to-peak displacement (Peak 2), while on the non-preferred limb side significantly positive correlated with peak displacement (Peak 1). These findings could indicate that the postural re-stabilization on the non-preferred (stabilizing) limb side is influenced by the initial CoP displacement (Peak 1), while the preferred limb side is influenced by over-compensation of movement such as peak-to-peak displacement (Peak 2). It may be assumed that the CoP displacement would also play an important role in re-stabilization.

This is one of the first studies which evaluate re-stabilization time in regards to the different roles of the lower limbs during unexpected lateral perturbations in physically active individuals without limb impairments. However, in order to confirm these results, further studies need more detailed views on the role of laterality in stabilization tasks in athletes. We can conclude that the observed shorter re-stabilization time on the non-preferred limb side is due to the stabilization role of the non-preferred limb.

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