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Original Article

Postural stability – a comparison between rowers and field sport athletes

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Abstract:
Postural stability (PS) is an important function for maintaining equilibrium during periods of standing still, locomotion, and any motor activities that require high degree of balance. High PS is essential in different sports for the regulation of voluntary movement and for improving athletic physical condition and performance. Purpose: The purpose of this study was to compare the static PS of elite rowing athletes and field sport athletes. Methods: A total of 90 elite athletes (age: 23.9 ± 1.97 years; body height: 174.9 ± 8.9 cm; body weight: 67.7 ± 12.03 kg) were divided into Rowing (N = 47) and Field sport (N = 43) athlete groups. Static PS parameters were assessed with a static double-leg and single-leg standing stability test on a force plate platform. Results: The multivariate analysis of variance showed a general stability difference between the groups ($F = 13.255$; $P \leq 0.0001$), in double leg stability ($F = 16.735$; $P \leq 0.0001$), and left leg ($F = 15.097$; $P \leq 0.0001$) stability parameters. When analyzing variables separately, significant statistical differences were observed in favor of the Rowing group in double leg sway area ($p = 0.017$; $ES = -0.07$), double leg center of force (COF) traveled way ($p \leq 0.0001$; $ES = -27.42$), length function of surface ($p \leq 0.0001$; $ES = -26.86$), right leg ML displacement ($p = 0.030$; $ES = -0.46$), left leg sway area ($p = 0.030$; $ES = -0.44$), left leg COF traveled way ($p \leq 0.0001$; $ES = -60.63$), left leg AP displacement ($p = 0.043$; $ES = -0.44$). Conclusion: These results underline the differences in rowing and field sport athletes in terms of static PS. The characteristics of sport and competition may affect PS, and it is important to adjust training modalities for the required level of PS in every sport, especially in rowing.

Key Words: biomechanics, exercise, motor control, elite athletes

Introduction

Postural control is defined as the ability to maintain the center of mass (COM) within the base of support with minimal postural sway, which requires proper functioning of the sensory (visual, somatosensory, and vestibular) systems, cognitive processing, and movement strategies (Horak, 2006). The body axis corrections by the aforementioned postural control mechanisms as a consequence of the bodily dynamics result in minute yet continuous oscillations when standing, which plays an important role in the pressure distribution on the foot soles and the efficiency of the venous return. Standing posture is a complex motor skill that involves the coordination of sensory inputs and one or more body segments and (Winter et al., 2003). Thus, postural control during standing requires maintaining Center of pressure without having to change the base of support (e.g., by taking a step or lifting feet from the surface). Standing posture stability depends on motor-sensory information, based on the body's internal representation by the central nervous system, which guarantees the system stability through adequate strategies (Ivanenko & Gurfinkel, 2018) . Thus, balance control is a complex sensorimotor function that requires the integration of vestibular, visual, and somesthetic information to generate a context-specific motor response, which in turn controls antigravity posture and gaze (Forbes & Chen, 2018) .

In sports activities, balance during different motor tasks involves dynamic postural control and requires automatic or reflex mechanisms in order to prevent imbalance via a tonic postural regulation, but it also mobilizes cognitive processes to anticipate postural adjustments (Massion, 1992). Postural stability (PS) is essential not only in everyday situations but also in almost all sports. Different sports have different balance requirements and demands, depending on the nature of the physical tasks involved (Hrysomallis, 2011). For athletes, both static and dynamic balance is important, as competitive sports like soccer, basketball, gymnastics, kayak and canoeing require optimal balance maintenance while performing dynamic tasks (Gerbino, Griffin & Zurakowski, 2007; Marinkovic et al., 2021; Stambolieva et al., 2012). Static balance is essential in shooting and archery, whereas dynamic balance plays an important role in combat sports, figure-skating, ice-hockey, handball, field-hockey, softball, squash, table tennis, and tennis (Zemkova, 2011). Most of the extant studies in this domain have focused on measuring postural sway in a stable and static position (Schmit, Regis & Riley, 2005). However, assessments of both static and dynamic balance help elucidate the effectiveness and the role of the

Corresponding Author: DRAGAN MARINKOVIC, E-mail: marinkovic@uns.ac.rs somatosensory-proprioceptive, vestibular and visual systems, as well as the athletes' neuromuscular efficiency (Horak, 2006; Hrysomallis, 2011; Matsuda, Demura & Uchiyama, 2008).

The importance of PS in some sports, for example ballet, dance, gymnastics etc., is obvious, but it is also important in events such as rifle shooting and ice hockey, and even those motor activities that do not have biomechanical relationships (Hrysomallis, 2011). Performances in some sports, such as pitching accuracy in baseball (Marsh, Papaioannou & Theodorakis, 2006) or ranking points in snowboarding (Platzer et al., 2009) do not require a high level of PS (was not associated with successful performance). Hrysomallis (2011) conducted a review about the differences of PS in some sports athletes and the level they compete at. According to a cross section of previous studies, gymnasts have better postural abilities than football players, swimmers and basketball players (Bressel et al., 2007). Previous research also concluded that there is no difference between football players and gymnasts and both revealed better PS performances than basketball players (Bressel et al., 2007; Matsuda, Demura & Uchiyama, 2008) and swimmers (Matsuda, Demura & Uchiyama, 2008), but they are inferior compared to ballet dancers (Gerbino et al., 2007). Negahban et al. (2013) suggested that top athletes may be more efficient in conditions that are consistent with their prior experience and training, reporting that rifle shooting has a more pronounced effect on static balance conditions in comparison to taekwondo. Taekwondo was also compared with tennis, since these sports practices contrast balance strategies and it was found that those involved with taekwondo display greater stability than tennis athletes (Fong et al., 2014; Patti et al., 2018). Other combat athletes, such as judokas, displayed better results on PS requirements than dancers whose pronounced characteristic is maintaining good PS during a choreography performance, an area that has been researched widely (Anjos & Ferraro, 2018; Ferrufino et al., 2011; Sofianidis, Dimitriou & Hatzitaki, 2017).

Rowing involves propelling a boat through water using one or two oars, which requires cyclical movements that can be performed by one or more rowers sitting with their backs facing the direction of motion. As rowers perform strenuous activity while seated on an unstable surface, this places considerable demand on their upper-body posture. The rowing stroke is performed primarily in the sagittal plane, and comprises of four distinct phases—catch, drive, finish, and recovery. It is a cyclical movement that involves sequential contributions of different body segments like arms, legs and body to propel the rowing boat forward through the water. Rowing not only requires teamwork and endurance, but also balance and stability, which is essential for safety as well as for effective rowing. Proper centre of mass control is thus important in rowing and canoeing, as well as in equestrian sports, i.e., in all sporting activities where biomechanical stability is needed to maintain balance in the sitting position (Zemkova, 2011). The unstable water support and the complex interplay of forces acting on the man−boat system pose a great challenge to postural balance, which can be endangered by capsizing, particularly in the frontal plane. However, it is impossible to reach a certain level of mastery of any technique involving motor action without an effective level of body position maintenance in the balance space. Balance is one of the main types of motor coordination to be mastered by rowers when learning and training (Stambolieva et al., 2012) and it can be evaluated via static postural tasks with varying levels of difficulty.

For several years, great effort has been devoted to the study of biomechanics of rowing, including force application, stability, kinetics, kinematics, and muscle activation (Arumugam et al., 2020; Mattes et al., 2015; Yusof et al., 2020). However, to the author´s knowledge, research focusing specifically on the differences in PS of elite rowers compared to field athletes is limited. Therefore, the aim of the present study is to determine whether the PS of rowing athletes differs from that exhibited by elite athletes in field sports.

Material and methods

Participants A gender-balanced group of 90 healthy elite athletes were enrolled in the study. Exclusion criteria were: (i) history of neurological or musculoskeletal disorders; (ii) clinical conditions that could impair balance. The study sample was divided into the elite rowers group (ROWING; n=47) including international level male and female rowers, and elite field sport athletes group (CONACT; n=43) including elite male and female soccer, basketball, handball athletes. Each subject, after explanation of the experimental protocol, provided a written informed consent prior to participating in the study, in accordance with the Declaration of Helsinki and with the Novi Sad University Human Research Ethics Committee guidelines (ethical approval number: 234/2020).

Table 1. Characteristics of participants

Variables	TOTAL (n=90)	ROWING (n=47)	FIELD (n=43)	p
Gender (male/female)	45/45	24/23	21/22	
Age (years)	23.9 ± 1.97	23.73 ± 2.05	24.16 ± 1.89	0.30
Weight (kg)	67.77 ±12.03	67.41 ±12.51	68.17 ± 11.63	0.97
Height (cm)	174.9 ± 8.9	174.92 ± 9.44	174.87 ± 8.39	0.76
BMI (kg/m^2)	22.0 ± 2.64	21.85 ± 2.44	22.18 ± 2.87	0.55

Table note: Data is presented as AM ± SD. Abbreviations: AM, arithmetic mean; SD, standard deviation; p- p value of differences between groups.

Measurement protocol The testing was conducted at the Faculty of sport and physical education, University of Novi Sad, Serbia. All participates were tested in the morning before the beginning of their training season in indoor environmental conditions (temperature: 18–21°C; relative humidity: 40–60%). Before starting a performance task, general information about the examinees was recorded, including gender, age, height, weight. For height and weight measurements, participants were instructed to wear minimal clothing and remove all footwear. In addition, they were required to eat and drink sparingly as well as void their bladder/excrete as needed prior to presenting for assessment. For height and weight measurements, a stadiometer (0.1 cm accuracy, SECA Instruments Ltd, Hamburg, Germany). Static PS assessment with laboratory-grade 0.5 m Footscan® plate (RSscan International, Lammerdries, Belgium) with 4096 sensors and a scanning rate of up to 300Hz. The subject performed individual single and double leg task with three trials, each lasting 30 seconds with two-minute break between each trial. Tests present the gold standard in measuring balance, was used to obtain biomechanical parameters of static PS (Haas & Burden, 2000). All measurements were performed in triplicate, and the mean score was retained for subsequent evaluations and analyses. The sequence of performing the balance tasks was randomized. Software calculated the single and double leg Sway Area (cm²), Center of Force (COF) traveled way (mm), Medio-Lateral (ML) displacement (mm), Anterior-Posterior (AP) displacement (mm) and Length function of surface (LFS) only for double leg stability test. Length in function of surface (LFS), is defined as the correlation coefficient between the COP length and its surface, and provides good yield index about the precision of postural control and the energy used by the participant to stand steady (Lion et al., 2014).

Double leg The double leg test consisted of measurements of maintaining balance during quiet stance on a force plate. The subjects' task was to maintain a balanced position of the body in position with their hands placed on their hips while their gaze was directed at a certain point in front of the head. The knees had to be fully extended, however, they had to be active and not in the position of locking the joint. The following foot placements were used feet placed parallel in hip width. Standing balance tasks were chosen based on their varying difficulty and common use as stated in previous research and is cited as reliable (Bauer et al., 2008; Springer et al., 2007)

Single leg During the single leg tests participants stood on their left or right foot, as required, in the centre of the board while the other foot was lifted with the big toe placed alongside the medial malleolus of the supporting leg. An upright posture was required, head straight, hands on hips and eyes open. Previous studies have used single leg stability test as reliable and valid for PS assessment (Troester, Jasmin & Duffield, 2018; Verhagen et al., 2005)

Statistical Analysis A priori, the G*power 3.1 power analysis software determined the minimum sample size (n = 36). The Kolmogorov-Smirnov test confirmed that all data was normally distributed. Thus, for age, body mass, BMI and height, descriptive statistics were calculated. In addition, the univariate analysis of variance (ANOVA) was performed to test the differences between groups on the selected variables. Moreover, the significance of the differences between subsamples was tested using and post hock Least Significant Difference (LSD) test. The effect size (ES) of each variable was assessed by calculating Cohen's d within each group, whereby 0.2, 0.2−0.6, 0.6−1.2, 1.2−2.0, 2.0, and 4.0 was defined as trivial, small, moderate, large, very large, and extremely large effect, respectively (Hopkins et al., 2009). Multivariate analysis of variance (MANOVA) was applied to determine the quantitative differences between variables system of Double leg stability test; Single leg stability test (separated for left and right leg); Double & Single leg stability test for two divided groups. Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) ver. 22 was used for all statistical tests with the significance level set to $p \leq 0.05$.

Result

Results of static PS parameters from ANOVA (Table 2) indicated a significant group (ROWING vs. FIELD) differences interaction for Sway Area (F = 5.882, p = 0.017), COF traveled way (F = 47.645, p < 0.001) and Length function of surface (F = 19.110, p < 0.001) all favoring ROWING group. The analysis did not show any significant differences in ML displacement (F = 0.329, p = 0.568) and AP displacement (F = 98.160, p < 0.001).

Table 2. Group differences in Double leg static stability test

Group		AS ± SD	ES	% diff	F	p
Sway Area (cm²)						
	ROWING	0.22 ± 0.43	-0.07	-12.77	5.882	0.017*
	FIELD	0.25 ± 0.04				
COF traveled way (mm)						
	ROWING	80.66 ± 0.71	-27.42	-21.19	47.645	0.000*
	FIELD	99.78 ± 0.67				
ML displacement (mm)						
	ROWING	6.11 ± 5.48	0.06	4.52	0.092	0.762
	FIELD	5.84 ± 2.33				
AP displacement (mm)						
	ROWING	8.33 ± 4.84	0.12	5.93	0.329	0.568
	FIELD	7.85 ± 2.73				
Length function of surface (LFS)						
	ROWING	43.55 ± 0.6	-26.86	-23.80	19.110	0.000*
	FIELD	55.35 ± 0.1				

*Table note: Result test presented as AM ± SD. Abbreviations: AM, arithmetic mean; SD, standard deviation; ES, effect size for differences between the groups; F, F-test statistics; p, probability value; *, significant differences at p < 0.05.*

When examining the results for PS parameters in Right leg static test (Table 3), only significant differences between groups were in ML displacement (F = 4.881, p = 0.030). Moreover, result indicate no statistical differences in Sway Area (F = 3.351, p = 0.07), COF traveled way (F = 0.109, p = 0.742), AP displacement (F = 0.130, p = 0.719).

Table 3. Group differences in Right leg static stability test

Group		AS±SD	ES	% diff	F	p
Sway Area (cm^2)						
	ROWING	0.51 ± 0.12	-0.21	-11.11	3.351	0.070
	FIELD	0.57 ± 0.11				
COF traveled way (mm)						
	ROWING	479.78 ± 2.40	-3.04	-1.59	0.109	0.742
	FIELD	487.48 ± 2.63				
ML displacement (mm)						
	ROWING	18.5 ± 3.86	-0.46	-9.47	4.881	0.030*
	FIELD	20.34 ± 4.14				
AP displacement (mm)						
	ROWING	28.29 ± 7.97	0.07	2.11	0.130	0.719
	FIELD	27.70 ± 7.65				

*Table note: Result test presented as AM ± SD. Abbreviations: AM, arithmetic mean; SD, standard deviation; ES, effect size for differences between the groups; F, F-test statistics; p, probability value; *, significant differences at p < 0.05.*

Large differences were indicated in favoring the ROWING group in Sway Area (F = 4.907, p = 0.030), COF traveled way (F = 55.313, p < 0.001) AP displacement (F = 4.201, p = 0.043), compared to FIELD group (Table 4). However, in ML displacement there were no differences (F = 1.197, p = 0.277).

Table 4. Group differences in Left leg static stability test

Group		AS±SD	ES	% diff	f	p
Sway Area (cm^2)						
	ROWING	0.55 ± 0.12	-0.44	-10.34	4.907	0.030*
	FIELD	0.61 ± 0.15				
COF traveled way (mm)						
	ROWING	277.30 ± 4.34	-60.63	-57.25	55.313	0.000*
	FIELD	499.73 ± 2.66				
ML displacement (mm)						
	ROWING	19.17 ± 5.55	-0.23	-6.07	1.197	0.277
	FIELD	20.37 ± 4.82				
AP displacement (mm)						
	ROWING	26.37 ± 7.77	-0.44	-12.15	4.201	0.043*
	FIELD	*29.78 ± 7.97*				

*Table note: Result test presented as AM ± SD. Abbreviations: AM, arithmetic mean; SD, standard deviation; ES, effect size for differences between the groups; F, F-test statistics; p, probability value; *, significant differences at p < 0.05.*

Results of MANOVA in different sets of variables (Table 5) indicate a significant difference between two groups in Double leg stability parameter (F = 16.735, p < 0.001), Left leg stability parameter (F = 15.097, p < 0.001) and in set of Double & Single leg stability parameters (F = 13.255, p < 0.001). The analysis did not show any significant differences in set of Right Leg stability parameters (F = 1.796, p = 0.137).

Table 5. Multivariate analysis of variance in different stability segments

Group	Value	ETA	F	p
Double Leg stability	0.559	0.441	16.735	0.000*
Right Leg stability	0.922	0.078	1.796	0.137
Left Leg stability	0.585	0.415	15.097	0.000*
Double & Single leg stability	0.326	0.674	13.255	0.000*

*Table note: Result MANOVA test presented as F, F-test statistics; p, probability value; *, significant differences at p < 0.05.*

Discussion

The aim of the present study was to determine difference in static PS between elite rowing athletes and elite field athletes. Statistically significantly better values of most of variables were noted for rowers, indicating that they have higher PS two of three tests. According to all PS parameters examined in this study, rowers experienced smaller oscillations during the Double leg test, Left leg stability test and in set of Double & Single leg stability parameters. It is also worth noting the LFS assessment findings, which suggest that rowers have exceptional control over their COF in double leg stability test. Results also indicate that only in Left leg stability test, differences were not statistically different between groups.

Even though the current results can be attributed to many factors, given the conditions under which rowers train and compete, they point to some definitive conclusions. As noted by extant research involving similar samples (Chung, 2015), due to the highly unstable conditions under which rowing is performed, athletes are continually required to establish and maintain balance, which not only affects their rowing technique, but also the performance outcome. Although the boat allows rowers to maintain largely static balance, water surface is inherently unstable, necessitating constant rebalancing. Moreover, as rowing is an outdoor sport, wind and other environmental conditions further contribute to the complexity of movements that need to be performed to maintain PS, which is one of the key considerations for S&C coaches (Nugent et al., 2020). It must also be noted that PS requirements also differ depending on the number of rowers in the boat, whereby the already complex technique and mechanics of rowing individual athletes are required to master must be further coordinated with those of other team members. This is in line with the findings yielded by other studies focusing on sports in which the surface and training conditions, as well as the training procedure itself, are unstable. Thus, in all sports activities involving unstable surface where it is necessary to maintain a stable posture, the need for core stability is greater.

Extant studies on the biomechanics of rowing indicate that this sport exposes the athlete to a highly unstable environment, as the boat is destabilized by removing the oar(s) from the water during each "tap down," thus challenging rower's core stability (Nugent et al., 2020). From the biomechanical point of view, the primary aim of the rowing techniques is controlling the motion and producing power and force. Propulsive force is generated at the foot stretcher where rowers strap their feet onto the boat frame. As this force acts primarily in the horizontal plane, it must be efficiently transferred through the trunk to the oar(s) during the rowing stroke (Soper & Hume, 2004). According to (Kleshnev, 2000), elite rowers generate 32.2% of the total propulsive force by their trunk. As most of this force should be stabilized by activating the trunk muscles, this promotes stability and postural control. Rowing athletes produce movement in four distinct phases, with the first (the catch phase involving rotation and lateral bending of the spine) providing the initial propulsion to the boat (Thompson & Wolf, 2016). To increase the stability of the upper thoracic region (Strahan et al., 2011) and optimize rowing stroke length (SL) (Mazzone, 1988) maximal flexion occurs at the hips. During the drive phase, the hip and back extensor muscles help to further the boat propulsion, but also assist with maintaining balance and stability through trunk activation (Turpin et al., 2011). The drive phase is followed by the finish phase during which the legs and trunk are fully extended (Thompson & Wolf, 2016). Hence, the trunk flexor muscles are particularly important in this phase as they help decelerate trunk extension during the layback part of the stroke (Turpin et al., 2011). The opposite phase of the drive phase is recovery period when the rowing boat is moving at its greatest velocity. Consequently, it is crucial that the boat is balanced to prevent the oar(s) making field with the water surface, which would increase drag and thus reduce boat velocity (Soper & Hume, 2004). To optimize the postural balance in all stages, the rower's body should be positioned according to temporal and spatial characteristics and circumstances and all his/her movements must be performed in a way that fully realizes his/her physiological potential. Synchronization and stabilization of rowing movements results in a functional and efficient performance, irrespective of its aesthetic value (Nolte, 1991). To achieve an efficient and long stroke, the rower has to be as horizontal as possible so that the vertical COG displacement is minimized without shortening the stroke length. PS as a very pronounced ability in such a training and competition regime is necessary for the rower to constantly maintain the quality of movement without atypical perturbations and COG deviations during rowing. Therefore, it can be said that the qualitative ability of the trunk muscles to provide core stability is one of the key requirements for success in this sport.

Greater PS in rowers can also be attributed to the emphasis on balance and core stability during their entire sports career. Empirical evidence suggests that the different techniques employed in their training program lead to the development of a different sensory perception model. Core stability training one of main strategy and often performed on different unstable surfaces such or as neuromuscular training program. However, a more rowing-specific training form of PS exercise can be achieved in a rowing boat using technical movement such as catch, drive, and finish phase tap downs.

Owing to the biomechanics of rowing and the techniques involved, as well as the neuromuscular requirements and the conditions in which rowing is performed, the PS mechanism in rowers is significantly more developed than in other athletes. Therefore, it can be concluded that the overall structure of rowing as a sport imposes competition and training demands that directly encourage improvements in PS, which can thus serve as a reliable assessment factor.

The results obtained in this study have both clinical and practical implications during training as well as in competitive settings. The degree to which rowing technique can be improved is largely conditioned by the athlete's PS, which determines the stroke efficiency. An efficient rowing technique requires well-developed motor skills and optimal morphological characteristics, including PS. Thus, if PS is used as one of the assessment criteria, rowers' condition can be more objectively evaluated, and any measures to improve core stability can be implemented.

Conclusions

Based on our findings it can be concluded that rowing training and competition may be beneficial for improving PS through the development of proprioception and vestibular functions which organize postural patterns in different biomechanical requirements. According to that, organization of the PS depends on training that develops sensory motor adaptabilities in accordance with environmental conditions and challenges imposed by each sport. In recent years several authors have had research published documenting sports training effects on PS (Hrysomallis, 2011). Rzepko et al. (2019) and that specific sports disciplines are able to improve specific balance performance and specific sensor abilities, especially task specific neural adaptations at the spinal and supraspinal levels (Rzepko et al., 2019). Observations of our findings, when interpreted with attention, indicate one of the explanations why rowing athletes have better PS could be in those training and sport characteristics which influence on improving neuromuscular coordination, joint position and learning to pay attention to biomechanical cues that can lead to the superior PS of elite athletes (Bressel et al., 2007).

This analysis does not enable us to evaluate differences in dynamic PS, which is important in so many sports, as the research explored only static PS. Our work in this study clearly has limitations, but despite this, we believe our study could be a worthwhile starting point for future research as a way to define PS in different sports. The evidence collected from this study points towards the idea of the importance of PS in different sports, especially in field sports. Our research findings suggest this could be a useful aid for performance specialists and strength and conditioning coaches because at present some training programs do not take in to account stabilization and balance as a way of improving performance and preventing injury. The second limitation pertains to the omission of other biomechanical, kinematic, and kinetic parameters from the analyses, which was necessary due to the difficulty of collecting data in a real-time environment. These shortcomings should thus be addressed in future studies in this field. It would also be beneficial to examine the effects of different age and gender categories on PS, as well as capture different visual and tactile information on PS measured by kinematic and kinetic instruments. The findings yielded would help ascertain if the maintenance of static and dynamic PS contributes to the maturation of the sensorimotor system or to a higher PS in different age categories and in different sports.

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