

POSTURAL BALANCE DURING QUIET STANCE AND STANDING SHOOTING POSITION IN BIATHLETES

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Abstract

Postural balance is crucial for shooting accuracy and often determines the biathlete's final result during the competition. The aim of the study was to (1) examine the postural balance of 11 biathletes and 12 physically active, untrained subjects during quiet stance in four conditions (standing in footwear with eyes open, standing in footwear with eyes closed, standing barefoot with eyes open, and standing barefoot with eyes closed) and (2) assess postural balance in biathletes in the standing shooting position. Postural balance was examined using the Zebris FDM-2 Force Distribution Measuring System. Biathletes had a significantly better stance stability, as evidenced by less body sways during the quiet stance than non-athletes. In both groups, the footwear did not significantly affect the postural balance parameters. Eye closure caused similar increase in postural balance parameters in biathletes and non-athletes, which confirms a significant contribution of visual information to postural balance control comparable in both groups. The standing shooting position of biathletes is characterized by greater body sways in the cross-shooting direction than in the shooting direction.

Key words: *biathlon, postural balance, standing shooting position, body*

Introduction

The biathlon, an Olympic sport, combines two elements: exhausting physical exercise (cross-country skiing) and a task that requires high concentration and precision (shooting). Numerous analyses of the shooting position in biathletes indicate that the postural balance is crucial for the accuracy of shooting (Ihalainen et al., 2018; Mononen, Konttinen, Viitasalo, & Era, 2007) and thus often determines the athlete's final result in a biathlon competition. The results of the study carried out by Sattlecker et al. (2014) underline the essential role of low body and rifle sway for a successful basic biathlon standing shooting at rest. Furthermore, the authors observed that high levels of balance and rifle stability during precision shooting at rest are essential basic motor skills, promoting a stable standing position even in competitions. Experienced biathletes are characterized by a stable shooting position and small body sways. Sattlecker et al. (2014), when comparing the stability of the shooting position in biathletes at different sporting levels, observed that the youth group of biathletes is characterized by the higher center of pressure (COP) deviations in cross-shooting direction compared to more experienced biathletes (Word Cup squad and European Cup squad). According to the authors, the higher COP deviations observed indicate specific shortcomings

in the postural balance of youth biathletes. This result has also been confirmed in rifle shooters, although these athletes used different equipment and shooting technique. Elite-level air rifle shooters displayed a significantly better postural balance than less experienced shooters (Konttinen, Lyytinen, & Era, 1999; Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996) or non-shooters (Aalto, Pyykkö, Ilmarinen, Kähkönen, & Starck, 1990).

Studies conducted so far among biathletes have focused solely on the evaluation of body sways appearing immediately before and during shooting (Sattlecker et al., 2014; Sattlecker, Buchecker, Gressenbauer, Müller, & Lindinger, 2017). The issue of static postural balance in biathletes during quiet stance has not been addressed so far. We believe that long-term training not only improves the stability of the shooting position but may also result in some specific postural control strategy and postural adaptations, which will be observed during standard posturographic tests carried out in a bipedal upright position with both eyes open and closed. According to Kuczyński et al. (2009), the specific postural strategies of athletes may result from slight muscular adjustments to monitoring an instantaneous body vertical position with greater efficiency. The postural balance adaptations resulting from the training have been repeatedly observed in athletes of other disciplines, such as:

judo (Perrin, Deviterne, Hugel, & Perrot, 2002), taekwondo (Patti et al., 2018), dance (Perrin et al., 2002), volleyball (Kuczyński et al., 2009; Agostini, Chiaramello, Canavese, Bredariol, & Knaflitz, 2013), tennis (Patti et al., 2018) or pentathlon (Sadowska, Sacewicz, Lichota, Krzepota, & Ładyga, 2019).

Footwear and its type may have a significant impact on postural balance due to the influence of the quality of sensory feedback from the feet (Hijmans, Geertzen, Dijkstra, & Postema, 2007; Perry, Radtke, & Goodwin, 2007). A reduced ability to detect or attend to the sensory information impairs the ability to detect changes in upright standing and increases the incidence of falls (Wang, Watanabe, & Chen, 2016). Some studies report differences in quiet stance COP measures barefoot and in footwear (Brenton-Rule, Bassett, Walsh, & Rome, 2011) or between different types of footwear (Lord, Bashford, Howland, & Munroe, 1999), while several other studies found no significant difference between barefoot and shod conditions (Landry, Nigg, & Tecante, 2010) or between different types of footwear (Brenton-Rule et al., 2011; Wilson, Rome, Hodgson, & Ball, 2008). Bearing in mind the numerous but ambiguous reports on the impact of footwear on postural balance (Brenton-Rule et al., 2011; Landry et al., 2010) and the key role of postural balance in shooting, in this study we decided to verify whether footwear significantly affects the postural balance in biathletes. Moreover, body sways in the standing shooting position in biathletes were analyzed. The aim of this study was to assess the static postural balance during quiet stance among biathletes and non-athlete controls, including an analysis of the impact of vision and footwear on postural balance control and the assessment of the postural balance of biathletes in the standing shooting position.

Methods

Participants

The study involved 11 biathletes (6 female and 5 male; mean age: 19.5 ± 1.7 years),

all members of the Polish youth biathlon team. The body height and mass of the biathletes were 172.5 ± 5.9 cm and 61.6 ± 6.9 kg, respectively.

The control group was composed of 12 physically active, untrained subjects (7 female and 5 male; mean age: 22.8 ± 1.6 years) who did not have previous experience in biathlon or shooting and did not practise sports professionally. The body height and body mass of the control group were 173.3 ± 10.0 cm, and 68.6 ± 7.1 kg, respectively.

Written informed consent was sought from all participants, or legal guardians in the case of underage subjects. The protocol of the study conformed to the recommendations of the Declaration of Helsinki and was approved by the local Bioethics Committee.

Procedure

Prior to the study, each participant was provided with detailed information about the aims of the

study, and the research methodology and was familiarized with the testing procedure. Each participant was examined individually.

Postural balance was examined using the Zebris FDM-2 Force Distribution Measuring System from the Body Posture Laboratory at the Regional Centre for Research and Development of the University College in Biała Podlaska. As the subject stood on the platform (dimensions: $212 \times 60.5 \times 2.1$ cm; number of miniature force sensors: 15,360), the force exerted by their feet was recorded by the sensors at a sampling rate of 120 Hz. Postural balance during quiet stance was evaluated in four conditions: "standing in footwear with eyes open", "standing in footwear with eyes closed", "standing barefoot with eyes open", and "standing barefoot with eyes closed". During each postural balance measurement, the participant remained still on the platform, in a comfortable foot position with arms in front of the body, as in the Romberg test. The order of completion of the four tasks was randomised for all participants.

Postural balance in the standing shooting position was evaluated only in the group of biathletes. The athlete was asked to assume a comfortable standing shooting position on the platform and aim at the target placed at a 10-m distance after hearing the command. All biathletes were right-handed, which determined the same foot position in the shooting position. In shooting position, medio-lateral (ML) direction corresponds to in shooting direction, and antero-posterior (AP) direction corresponds to in cross-shooting direction.

Each measurement lasted 40 seconds. The first and last five seconds of each recording were removed. The coordinates of the instantaneous centre of pressure (COP) were calculated with WinFDM Stance processing software (Table 1).

Table 1. Specification of analysed posturographic measures

Parameter	Description of parameter
<i>COP shifts</i>	
SP [mm]	Sway path length of COP
V [s/m]	Average velocity of COP
<i>COP surface area</i>	
AoE [mm ²]	Area of centre of pressure (calculated from COP shifts in such a way that 95% of data are within ellipsoid and 5% are outside of it)
WoE [mm]	Width of ellipse (length of ellipse in mediolateral direction)
HoE [mm]	Height of ellipse (length of ellipse in anteroposterior direction)

Statistical analysis

Statistical analyses were conducted using STATISTICA 13.0 software (Dell, Statistica). The mean, standard deviations and 95% confidence intervals have been calculated for all analysed variables. Normality of distributions of the analysed variables was verified by the Shapiro-Wilk test. Due to the fact that the distributions of all variables describing COP shifts and COP surface area differed from the normal distribution, Box-Cox transformation was used to normalize these variables (Box & Cox, 1964). The data were analyzed using three-factor with repeated measures ANOVA and the eta-squared (η^2) effect sizes were calculated to express the amount of variance accounted for by one or more independent variables. The within-subjects factors were: vision (eyes opened, eyes closed) and the footwear (in footwear, barefoot), with the between-subjects factors being two groups (biathletes, control). Statistical significance was set at the $p < 0.05$ level for all tests.

Results and discussion

Due to the fact that the groups were not sex-homogeneous, statistical analyses started by verifying whether the sex variable differentiated the results. For each analyzed parameter, the sex was not a factor significantly affecting the obtained results. ANOVA did not show statistically significant interactions between factors. Also there was no significant difference in the main effect of footwear in all variables (table 2).

Table 2. The main effects of between-subject factor (group: biathletes, controls) and two within-subjects factors (vision: eyes open, eyes closed; footwear: in footwear, barefoot) for posturographic measures recorded under four conditions in biathletes and non-athletes. None of the interaction effects have been statistically significant.

Parameter	Group	Vision	Footwear
<i>COP shifts</i>			
SP [mm]	F=0.02 p=0.8851 $\eta^2 < 0.01$	F=50.42 p<.0001*** $\eta^2 = 0.54$	F=0.23 p=.6339 $\eta^2 < 0.01$
V [mm/s]	F=0.02 p=0.9712 $\eta^2 < 0.01$	F=47.89 p<.0001*** $\eta^2 = 0.53$	F=0.26 p=.6138 $\eta^2 < 0.01$
<i>Surface area of the COP</i>			
AoE [mm ²]	F=17.01 p=.0002*** $\eta^2 = 0.29$	F=8.98 p=.0046** $\eta^2 = 0.18$	F=0.01 p=.9165 $\eta^2 = 0.01$
WoE [mm]	F=35.69 p<.0001*** $\eta^2 = 0.50$	F=5.68 p=.0217* $\eta^2 = 0.12$	F=0.48 p=.4893 $\eta^2 = 0.01$
HoE [mm]	F=3.04 p=.0884 $\eta^2 = 0.07$	F=8.72 p=.0051** $\eta^2 = 0.17$	F=0.65 p=.4240 $\eta^2 = 0.02$

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

The values of two of the three parameters describing surface area of COP (AoE, WoE) were significantly lower in the group of biathletes than in the control group (group effect for AoE: 17.01; $p = .0002$; group effect for WoE: $F = 35.69$; $p < .0001$). Eye closure resulted in a statistically significant increase in all analyzed parameters, comparable in both groups.

The recorded mean values for posturographic measures are shown in Table 3.

Table 3. Means and standard deviations for posturographic measures recorded under four conditions in biathletes and non-athletes.

Parameter	Group	Open eyes		Closed eyes	
		In footwear	Barefoot	In footwear	Barefoot
		M (SD)	M(SD)	M (SD)	M (SD)
<i>COP shifts</i>					
SP [mm]	B	149.0 (41.2)	155.5 (50.4)	265.9 (79.4)	253.2 (97.7)
	C	165.4 (39.4)	169.5 (64.8)	255.9 (111.2)	221.7 (71.0)
V [mm/s]	B	4.9 (1.3)	5.1 (1.8)	8.9 (2.7)	8.4 (3.4)
	C	5.5 (1.3)	5.6 (2.7)	8.5 (3.7)	7.3 (2.3)
<i>COP surface area</i>					
AoE [mm ²]	B	71.6 (44.1)	73.9 (29.5)	113.8 (30.7)	117.9 (53.6)
	C	180.6 (108.0)	147.1 (75.3)	172.0 (77.2)	190.9 (88.6)
WoE [mm]	B	5.9 (1.8)	6.5 (1.5)	6.6 (1.1)	7.7 (2.4)
	C	10.2 (2.7)	10.2 (2.4)	10.8 (3.2)	11.0 (3.0)
HoE [mm]	B	14.9 (6.8)	14.4 (4.2)	21.8 (5.2)	19.0 (4.2)
	C	21.6 (9.0)	17.5 (5.7)	19.5 (5.0)	22.1 (7.8)

B - biathletes; C - control group

The mean values for posturographic measures obtained in the standing shooting position in the group of biathletes are presented in Table 4. Area of the body sway in the standing shooting position obtained 109.2 ± 55.0 . Shooting positions are characterized by greater body sways in (anteroposterior) AP direction (17.2 ± 4.8) than in (mediolateral) ML direction (7.8 ± 2.6).

Table 4. Means, standard deviations and 95% confidence intervals for posturographic measures recorded in the standing shooting position in biathletes

Parameter	M \pm SD	95% IC
<i>COP shifts</i>		
SP [mm]	348.3 \pm 154.1	(244.8; 451.8)
V [mm/s]	11.5 \pm 5.1	(8.0; 14.9)
<i>COP surface area</i>		
AoE [mm ²]	109.2 \pm 55.0	(72.1; 146.1)
WoE [mm]	7.8 \pm 2.6	(6.1; 9.6)
HoE [mm]	17.2 \pm 4.8	(13.9; 20.4)

The results of our study showed that regardless of the measurement conditions (in footwear/barefoot, eyes open/eyes closed), biathletes were characterized by significantly lower values of COP surface area (AoE and WoE) during quiet standing than non-athletes. According to Menegoni et al. (2011), lower values of parameters describing the magnitude of COP displacement are evidence of a greater effectiveness of the postural system. Our observations are consistent with the results of the studies conducted among archers (Stambolieva, Otzetov, Petrova, Ikonov, & Gatev, 2015) rifle shooters (Aalto et al., 1990; Su, Wu, & Lee, 2000) and pentathletes (Sadowska et al., 2019). Stambolieva et al. (2015) observed lower body sway amplitude in archers compared to the non-athletes in posturographic measurements with open and closed eyes, both on stable and foam support. In turn, Aalto et al. (1990) and Su et al. (2000) noted significantly lower values of COP velocity in shooters compared to the control group. In our earlier study, which aimed to compare the postural balance of pentathletes and non-athletes, we observed that pentathletes were characterized by significantly lower values of analyzed posturographic measures than those recorded in the control group (Sadowska et al., 2019). In this study, we have made similar observations among biathletes. We assume that the differences in surface area of COP between biathletes and non-athletes are the result of the training undertaken. Success in shooting sport (like rifle shooting, gun shooting, pentathlon, archery) is determined by high level of postural balance, coordination of the segments of the body and high concentration of attention at the time of execution of the shot (Herpin et al., 2010; Stambolieva et al., 2015). Also, in the training of biathletes, a lot of attention is paid to mastering the ability of proper body stabilization. For this purpose, trainers are assisted by specialistic equipment i.e., force platforms to determine and modify body sway, video analysis of body position and laser tracking of the rifle barrel (Laaksonen, Finkenzeller, Holmberg, & Sattlecker, 2018).

In this study, footwear was not a factor significantly affecting the postural balance in any of the examined groups. These observations do not confirm our previous results obtained in the group of pentathletes (Sadowska et al., 2019). The opinions of other authors on the impact of footwear on postural balance are also divided (Brenton-Rule et al., 2011; Landry et al., 2010). In this study, participants took measurements in comfortable, used everyday sports shoes. We assume that their sports shoes provided minimal interference with the natural movement of the foot due to their high flexibility, low heel to toe drop and low weight. It is probable that testing participants in new or conventional shoes may manifestly affect the postural balance. Nonetheless, the ambiguous results of the research indicate that this issue requires further research.

Sensory information about the posture from the somatosensory, visual, and vestibular systems are crucial for postural balance control (Collins & De Luca, 1995; Nashner, Black, & Wall, 1982). It has been reported that for most people (including athletes), the absence of visual feedback input impaired postural balance (among others: Paulus, Straube, & Brandt, 1984; Vuillerme, Burdet, Isableu, & Demetz, 2006). Approximately 80% of an individual's sensory perception is gathered by the visual system, which processes and integrates other sensory inputs to select a balancing strategy (Friedrich et al., 2008; Schmid, Nardone, De Nunzio, Schmid, & Schieppati, 2007). The significant increase in all analyzed parameters observed in this study, caused by eye closure, confirms that the visual system is the primary sensory information for maintaining postural balance.

In addition, in our study, we analyzed the body sways of biathletes in the standing shooting position. The standing position, as the most unstable of the biathlon shooting positions, is very difficult for shooting because the support area of the body is small. The standing shooting position demands from the athlete an exceptional sense of balance, as well as muscle control, which should be relatively relaxed, but also must give the necessary stability to the position so that the rifle moves as little as possible. Although numerous studies have shown that poor stance stability is associated with an unstable hold on the rifle, which results in poor and variable shooting (Sattlecker et al., 2014; Ball, Best, & Wrigley, 2003; Mononen et al., 2007), little attention has been devoted in the literature to detailed research and description of the standing shooting position of biathletes. Trainer elaborations contain instructions regarding the proper posture in the standing shooting position, as well as indicate the need to leave full freedom of choice (regarding posture) to the biathlete. In the few studies carried out so far, the authors found some features typical of the standing shooting position. Espig and Siebert (2012) analyzed variables of body sway in standing shooting position over one second before the shot. They analyzed the deviation of the COP in shooting direction (ML direction) and in cross-shooting direction (AP direction), as well as the load distribution between the front and rear foot. The results showed less body sway with greater load distribution on the front foot. Sattlecker et al. (2017) noted that, in the case of biathlon shooting, muscle fatigue increases ankle joint motion, resulting in a more pronounced destabilization in

the AP than in the ML direction. The results of this study confirm the above observations. Evidence of significantly higher body sways in the standing shooting position in the AP direction (in cross-shooting direction) than in the ML direction (in shooting direction) is the nearly twice higher values of height of ellipse of COP (HoE) in relations to its width (WoE) recorded in this study. Also, Sattlecker et al. (2014), as well as Niinimaa and McAvoy (1983), observed that body sways in cross-shooting direction is significantly higher than in shooting direction.

Conclusion

To conclude, our data showed that biathletes had a significantly better stance stability than untrained controls, which is evidenced by less body sways during quiet stance in biathletes than non-athletes. Both in biathletes and non-athletes, the footwear did not significantly affect the postural balance parameters. Eye closure caused similar increase in postural balance parameters in biathletes and non-athletes, which confirms the contribution of visual information to postural balance control is significant and comparable in both examined groups.

In a standing shooting position, the biathlete's body sways are greater in cross-shooting direction than in the shooting direction.

The presented results are the first reports on postural stability of biathletes during quiet stance. In the future, it is worthwhile to conduct studies on a larger sample of biathletes, taking into consideration the impact of different types of footwear on the postural balance. We believe that the analysis of body sways in the standing shooting position of biathletes presented here will help trainers in teaching the shooting position, as well as correcting reoccurring mistakes. However, it should be remembered that the measurements we carried out took place in sports shoes. In natural conditions (on skis or roller skis), the body's sways are likely to change.

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