The impact of fatigue on static balance in people with chronic ankle instability

Małgorzata Kowalczyk, Aleksandra Truszczyńska-Baszak*

Faculty of Physiotherapy, Józef Piłsudski University of Physical Education in Warsaw, Warsaw, Poland.

Purpose: The aim of the study was to assess static postural stability under fatigue in subjects with chronic ankle instability – "copers" in comparison with healthy controls. *Methods*: We conducted a prospective study on a group of 60 young, physically active subjects, divided into 3 groups: I – 14 subjects with unilateral ankle instability, II – 15 subjects with bilateral ankle instability, III – 31 healthy subjects, without ankle instability. The fatigue trial was based on modified Short-Term Fatigue Protocol. Static stabilography was performed with the use of HUR platform. *Results*: showed an increase in the value of COP trace length after fatigue test in study population I. The level of COP trace length *Z* before fatigue was significantly lower than after fatigue. Subjects from study population I had higher levels of COP trace length *Z* in comparison with the control group. The main effect for the group also proved to be significant. Study population I had higher levels of COP trace length *Z* in comparison with the control group. For the measurement after fatigue, there was significant difference only between the study population I and the control group. *Conclusions*: The incidence of structural ankle instability was not correlated with functional instability. Subjects with ankle instability, or "copers", had good functional levels, enabling them to perform sports activities. "Copers" had weakened proprioception in static stabilography tests. Short and intense fatigue protocol weakened the ability to maintain balance in static stabilography test with eyes closed.

Key words: fatigue, proprioception, balance, neuromuscular control, chronic ankle instability, CAI, lateral ankle sprain, LAS

1. Introduction

Inversion injury of the ankle is the most common injury in people who do sport. These injuries result in up to 25% of absences in sports activity [19], [20] and 60% of young athletes have experienced at least one inversion injury [17].

The usual consequences of inversion injury are decreased sensorimotor control, including decreased proprioception, decreased muscle strength or decreased balance (reduced static and dynamic postural balance). These changes were observed both in subjects with a new sprain injury and in subjects with chronic ankle instability (CAI) [2], [11], [13], [16], [28]. Reduced sensorimotor control combined with an earlier injury to the lower extremity may lead to the worsening of

sports performance and may result in increased likelihood of another injury [1], [7], [12].

Athletes who have successfully regained high sports performance despite prior inversion injury or injuries and who do not have persistent symptoms, are referred to as "coopers" in the literature [29]. To prevent injury and to design appropriate treatment strategies it is essential to examine biomechanical parameters that differentiate CAI coopers and healthy subjects.

Muscle fatigue predisposes athletes to recurring inversion injuries. Muscle fatigue reduces the maximum voluntary contraction. Fatigue was found to reduce passive and active joint position sense in adults with healthy and stable ankles [8], [21]. Injury risk for subjects with CAI is significantly higher [14], [26]. Studies have found that fatigue reduces motor control [4], joint position sense and muscle reaction during activity [30].

Changes induced by fatigue may result in inappropriate positioning of the lower extremity and in difficulties in prompt reactions to changes in movements, therefore predisposing subjects to injuries [3], [4]. This study has impact to the current knowledge comparing to the existing literature as it brings insight in postural stability assessment of special group of active people "coopers" after CAI.

Aim of the study. The aim of the study was to assess static postural stability under fatigue in subjects with chronic ankle instability in comparison to healthy controls which is very important and useful physiotherapy practitioners in order to establish proper recovery and return to sport programs.

2. Materials and methods

After obtaining the consent to conduct the study by the Senate Research Ethics Committee no. 01-19/2017, we conducted a prospective study on a group of 60 young, physically active subjects, who we divided into 3 groups:
I. Subjects with unilateral ankle instability, $n = 14$ (5 females, 9 males),
II. Subjects with bilateral ankle instability, $n = 15$ (5 females, 10 males),
III. Healthy subjects, without ankle instability, $n = 31$ (10 females, 21 males).

We used the G∗Power 3.1.9.4. programme to establish whether the test power of the obtained results was sufficient. We calculated the effect size on the basis of the general stability index in three groups (group I $n = 14$, group II $n = 15$, group III $n = 31$) ($f = 0.47$). We used the analysis of variance scheme in the mixed pattern 3×2 (3 groups × 2 measurements) with $\alpha = 0.05$ to conduct the calculations. The estimated test power was 0.94, which proved that the studied sample was sufficient to conduct the analyses.

Characteristics of the I and II study populations, and of the control group are presented in Table 1.

The first inclusion criterion for participating in the study was: having a minimum of two episodes of ankle strain within the same lower extremity within the past 3 years (a minimum of one serious strain preventing from sports activity ≥ 21 days) [24], damaged anterior talofibular ligament and/or talocalcaneal ligament III°, confirmed with a medical imaging test of ultrasound and/or MRI. The second criterion was obtaining a score of a minimum of 60 points on the The Foot & Ankle Disability Index (FADI) and

on its sports module (FADI-S) [12]. The FADI and FADI-S are reliable, international questionnaires designed to assess functional limitations of subjects with CAI; to differentiate between healthy subjects and subjects with CAI and to monitor changes resulting from physiotherapy. The other criteria were having fully regained ability to do sports activity (a minimum of 6 months prior to the participation in the study) [30], being physically active subjects (a minimum of 2 hours of physical activity weekly, endurance or related to performed sports discipline), aged 18–35 years.

Table 1. Characteristics of study population I and study population II and the control group – age, body height, body mass, and BMI. There were no statistically significant differences between the groups

Variable	Study population I ($n = 14$)	Study population II ($n = 15$)	Control group ($n = 31$)
Age [years]	29.8 ± 4.6 21.0÷35.0	30.3 ± 5.0 18.0÷35.0	29.8 ± 3.4 24.0÷35.0
Body height [cm]	180.0 ± 9.0 160.0÷189.0	180.0 ± 10.0 170.0÷192.0	176.4 ± 9.1 161.0÷195.0
Body mass [kg]	70.0 ± 11.2 54.0÷82.0	76.1 ± 13.5 55.0÷100.0	74.5 ± 13.0 50.0÷107.0
BMI	22.8 ± 2.0 18.7÷25.2	22.3 ± 3.6 18.0÷30.2	23.8 ± 2.9 18.4÷32.0

Criteria for subject exclusion from study population and from control group were: recent injury or chronic pain of the locomotor system, surgery to a lower extremity, pain, swelling or effusion in a lower extremity joint, feeling of joint instability, fear of doing sports activity, active participation in physiotherapy, limitations to movement range in the joints of lower extremities, contraindications for fatigue test (i.e., recent myocardial infarction, unstable coronary thrombosis, hypertrophic cardiomyopathy, aortic stenosis, pulmonary hypertension, severe arrhythmia, pulmonary and/or peripheral embolism, advanced circulatory failure (NYHA IV), myocarditis, endocarditis, pericarditis, aortic aneurysm, acute inflammatory conditions, advanced systemic disease, disease of the locomotor system or neural disease that prevent performance of the test, ejection fraction below 30%, uncontrolled hypertension), professional sports performance.

Subjects interested in participation in the study completed a questionnaire on health and the FADI and FADI-S forms. 74 subjects were initially qualified for the study. Eight subjects did not report for the test and six subjects resigned during the test.

In Table 2, characteristics of the I and II study populations and of the control group regarding weekly

physical activity are presented; Foot & Ankle Disability Index (Table 2).

Table 2. Characteristics of study population I
and study population II and control group;
presenting weekly physical activity; FADI results and FADI-S results.
[*] Statistically significant results ($p < 0.05$) between study
population I and study population II and the control group
on the FADI-S group, though without clinical significance.
Remaining results did not reveal statistically
significant differences between the groups

Variable	Study population I ($n = 14$)	Study population II ($n = 15$)	Control group ($n = 31$)
Weekly physical activity [hours]	4.1 ± 1.9 2.0÷8.0	4.8 ± 3.2 2.0÷12.0	5.3 ± 2.6 2.0÷15.0
FADI	96.4 ± 3.6 90.4÷100.0	97.1 ± 4.0 88.5÷100.0	99.4 ± 2.4 86.5÷100.0
FADI-S	90.6 ± 8.5* 75.0÷100.0	91.4 ± 10.4* 71.9÷100.0	98.7 ± 5.1* 71.9÷100.0

The tests were performed at the Center for Functional Diagnostics of Carolina Medical Center in Warsaw. The person conducting the tests (MK) was a physiotherapist with 10-year experience.

Study protocol

The warm-up consisted of 10-minute cycling on a stationary bike as well as a 5-minute long exercise of subjects' choice. Then, the maximum jump height was determined (H_{max}). The subjects performed three vertical counter movement jumps (CMJ) on the AMTI dynamometer platform. The highest jump value from three trials (H_{max} [cm]) was chosen for analysis. Not reaching a minimum of 90% of maximum height in one of three jumps in two consecutive series was one of the criteria of stopping the fatigue test [22]. Static stabilography was performed with the use of HUR platform. Subjects took four trials of single leg stance lasting 30 s each (one trial for each leg with eyes open and with eyes closed). The aim of the trials was to assess the mechanism of maintaining balance on stable surface in trials with eyes open and with eyes closed.

The fatigue trial was based on modified Short-Term Fatigue Protocol (FAST-FP). The trial consisted of exercise that involve lower extremities. This protocol is universally used in trials aiming to assess landing parameters after jump [22].

The protocol is based on four exercises performed in a series:

1. Exercise: three counter movement jumps on the height of a minimum of 90% H_{max}. After each jump, subjects received information on their results;

2. Exercise: step up and down a stepper of a height of 30 cm in 30 seconds; the speed of the task was 200 beats per minute, timed with a metronome;
3. Exercise: five knee-bends to the position of 90° bend at the knees;
4. Exercise: proagility shuttle run 5 m–10 m–5 m.

The number of series depended on subjects' individual endurance; this allowed us to achieve optimal fatigue level for each subject. Subjects continued the fatigue protocol until one of the fatigue criteria was met: subject did not reach a minimum of 90% of maximal height in one of three jumps in two consecutive exercise series (the maximum height of jump was determined before the start of fatigue protocol), subject had ≥90% of maximum heart contraction (the maximum pulse was calculated with the following formula $HR_{max} = 202.5–0.53*$subject's age), subject refused to continue the trial.

The remaining criteria for terminating the fatigue test: pain in the chest, strong muscle pain or considerable tiredness, feeling faint, dyspnoea, breathing difficulties, sudden paleness or cyanosis, balance disorders, subject request to stop the fatigue test [22]. Subjects' heart rate was being registered during the fatigue test, too. The tests were monitored by a medical doctor, and a portable cardioverter defibrillator was available in the Functional Diagnostics lab.

Repeated biomechanical test

After the fatigue test, the subjects underwent the same biomechanical measurements which they had after the warm up (as discussed in point II). The measurements were taken immediately after the fatigue test so as not to allow the subjects to relax.

Analysed parameters:
• COP trace length O/Z – movement centre of pressure of feet onto the surface for trials with eyes open/closed;
• COP trace length O/Z – movement of centre of pressure of feet onto the surface for trials with eyes open/closed.

Statistical analysis

Statistical analysis was conducted in IBM SPSS25.0 programme. The authors performed: analysis of basic descriptive statistics, Shapiro–Wilk test for normality of distribution test, analysis of variance in a mixed design 3 groups × 2 measurements (F Snedecor distribution – probability distribution of a random variable F (degree of freedom, η_p^2 – effect size). Outliers were

excluded from the analyses (+/–3SD). Significantly difference p value was at $p < 0.05$.

3. Results

3.1. Static stabilography

Comparison of studied populations and the control group in respect of the movement of centre of pressure of feet onto the surface for trials with eyes open (COP trace length – O)

In order to analyse the differences between groups in respect of COP trace length – O, we conducted analysis of variance in the mixed scheme 3×2 (study population I vs. study population II vs. control group; measurement: before vs. after fatigue test).

The conducted analysis did not reveal main effect for COP trace length, $F(1.48) = 2.41$; $p = 0.127$; $\eta_p^2 = 0.05$. This means that COP trace length value before ($M = 1305.18$; $SE = 42.74$) and after fatigue test ($M = 1369.34$; $SE = 45.47$) did not differ significantly.

The main effect for the group also proved not to be significant, $F(2.48) = 0.40$; $p = 0.676$; $\eta_p^2 = 0.02$. Subjects from study population I ($M = 1387.28$; $SE = 77.91$), study population II ($M = 1318.43$; $SE = 71.66$) and control group ($M = 1306.08$; $SE = 49.73$) did not differ significantly in respect of the analysed variable.

The interaction of both variables proved significant, though, $F(2.48) = 6.94$; $p = 0.002$; $\eta_p^2 = 0.22$. Detailed analysis of simple effects showed an increase in the value of COP trace length after fatigue test in study population I ($F(1.48) = 12.75$; $p = 0.001$; $\eta_p^2 = 0.21$). We did not find differences between measurements before and after fatigue test in the control group ($F(1.48) = 0.04$; $p = 0.845$; $\eta_p^2 < 0.01$) and study population II ($F(1.48) = 2.21$; $p = 0.144$; $\eta_p^2 = 0.04$). The differences between groups in measurements taken before fatigue test ($F(2.48) = 0.69$; $p = 0.507$; $\eta_p^2 = 0.03$) after fatigue test proved insignificant ($F(2.48) = 2.84$; $p = 0.068$; $\eta_p^2 = 0.11$). The results are illustrated in Fig. 1 and descriptive statistics are presented in Table 3.
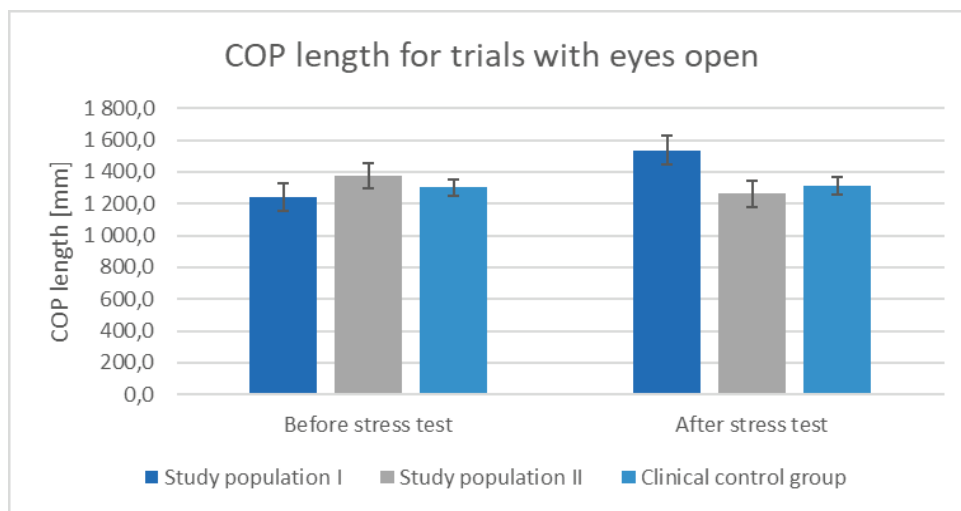

Fig. 1. Means and standard errors for the trace length of centre of foot pressure for trials with eyes open (COP trace length O) in the control group, study population I and study population II

Table 3. Descriptive statistics for the trace length of centre of foot pressure for trials with eyes open (COP trace length O)

					95% CI	
		M	*SD*	*SE*	*LL*	*UL*
COP [mm] trace length *O* – before fatigue test	Study population I	1239.81	308.96	85.40	1068.10	141.53
	Study population II	1374.84	279.44	78.56	1216.89	1532.80
	Control Group	1300.88	274.52	54.51	1191.28	1410.49
COP [mm] trace length *O* – after fatigue test	Study population I	1534.74	354.95	90.87	1352.04	1717.44
	Study population II	1262.01	135.61	83.59	1093.95	1430.06
	Control Group	1311.27	332.76	57.99	1194.66	1427.88

Comparison of studied populations and the control group in respect of the movement of centre of pressure of feet onto the surface for trials with eyes closed (COP trace length Z)

In order to analyse the differences between groups in respect of COP trace length Z, we conducted analysis of variance in the mixed scheme 3×2 (study population I vs. study population II vs. control group; measurement: before vs. after fatigue test).

The conducted analysis revealed significant main effect for COP trace length Z, $F(1.48) = 6.03$; $p = 0.018$; $\eta_p^2 = 0.11$. The level of COP trace length Z before fatigue test ($M = 3779.72$; $SE = 217.88$) was significantly lower than after fatigue test ($M = 4392.15$; $SE = 271.20$).

The main effect for the group also proved to be significant, $F(2.48) = 7.07$; $p = 0.002$; $\eta_p^2 = 0.23$. Subjects from study population I ($M = 5122.96$; $SE = 423.72$) had higher levels of COP trace length Z in comparison with the control group ($M = 3237.26$; $SE = 270.46$; $p = 0.001$), whereas there were no differences between subjects from study population I and study population II ($M = 3897.61$; $SE = 389.77$; $p = $

0.115) or between control group and study population II ($p = 0.511$).

The interaction of both variables proved insignificant, $F(2.48) = 2.82$; $p = 0.070$; $\eta_p^2 = 0.09$. In the study population I ($F(1.48) = 0.13$; $p = 0.723$; $\eta_p^2 < 0.01$) or the control group ($F(1.48) = 0.41$; $p = 0.527$; $\eta_p^2 = 0.01$) there were no differences in the levels of COP trace length Z between measurements before and after fatigue test. In the study population II ($F(1.48) = 10.09$; $p = 0.003$; $\eta_p^2 = 0.17$) this effect was statistically significant – after fatigue test there was an increase in levels of COP trace length Z.

Both in the measurements before fatigue test ($F(2.48) = 7.37$; $p = 0.002$; $\eta_p^2 = 0.24$) and after fatigue test ($F(2.48) = 5.08$; $p = 0.010$; $\eta_p^2 = 0.18$), there were statistically significant differences between groups, which confirmed the results obtained for the main effect for the group and the measurement. A detailed analysis of results revealed that for the measurement before fatigue test the level of COP trace length Z in the study population I was significantly higher than in the study population II ($p = 0.008$) and in the control
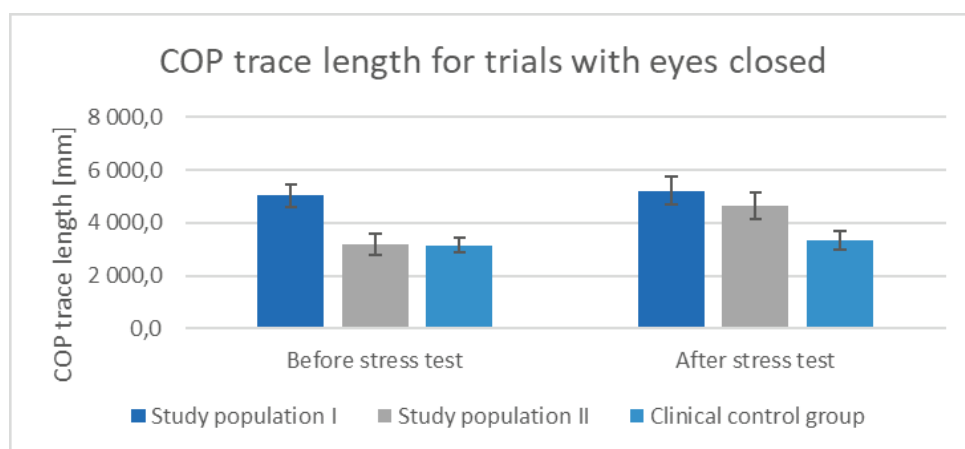

Fig. 2. Means and standard errors for the trace length of centre of foot pressure for trials with eyes closed (COP trace length Z) in the control group, study population I and study population II

Table 4. Descriptive statistics for the trace length of centre of foot pressure for trials with eyes closed (COP trace length Z)

					95% CI	
		M	*SD*	*SE*	*LL*	*UL*
COP [mm] trace length Z – before fatigue test	Study population I	5033.93	2588.12	435.41	4158.48	5909.38
	Study population II	3169.33	546.55	400.52	2364.04	3974.62
	Control Group	3135.92	1065.73	277.92	2577.13	3694.70
COP [mm] trace length Z – after fatigue test	Study population I	5211.98	2729.89	541.98	4122.26	6301.71
	Study population II	4625.88	2185.13	498.55	3623.49	5628.28
	Control Group	3338.59	946.13	345.94	2643.04	4034.15

group ($p = 0.002$), while there were no differences between the control group and the study population II ($p = 1.000$). For the measurement after fatigue test, there was significant difference only between the study population I and the control group ($p = 0.016$). The differences between study population I and study population II ($p = 1.000$) and the study population II and control group ($p = 0.017$) were insignificant. The results are illustrated in Fig. 2 and descriptive analysis is presented in Table 4.

Comparison of studied populations and the control group in respect of the ellipse surface area for trials with eyes open (C90 Area O)

In order to analyse the differences between groups in respect of C90 Area O, we conducted analysis of variance in the mixed scheme 3 × 2 (study population I vs. study population II vs. control group; measurement: before vs. after fatigue test).

The conducted analysis did not reveal main effect for C90 Area O, $F(1.45) = 0.97$; $p = 0.331$; $\eta_p^2 = 0.02$. This means that there were no statistically significant differences between measurements before ($M = 581.16$; $SE = 36.40$) after fatigue test ($M = 621.27$; $SE = 41.94$).

The main effect for the group also proved not to be significant, $F(2.45) = 0.47$; $p = 0.626$; $\eta_p^2 = 0.02$. Subjects from study population I ($M = 550.27$; $SE = 69.73$), study population II ($M = 631.31$; $SE = 60.39$) and control group ($M = 622.07$; $SE = 40.26$) did not differ significantly in respect of the C90 Area O.

The interaction of both variables proved significant, though, $F(2.45) = 3.51$; $p = 0.038$; $\eta_p^2 = 0.14$. We did not find differences between measurements before and after fatigue test within the study population II ($F(1.45) = 0.95$; $p = 0.335$; $\eta_p^2 = 0.02$) and control group ($F(1.45) = 0.12$; $p = 0.736$; $\eta_p^2 < 0.01$). In the study population I ($F(1.45) = 6.05$; $p = 0.018$; $\eta_p^2 = 0.08$), however, we found an increase in the C90 Area O after fatigue test in comparison to the measurement before fatigue test.

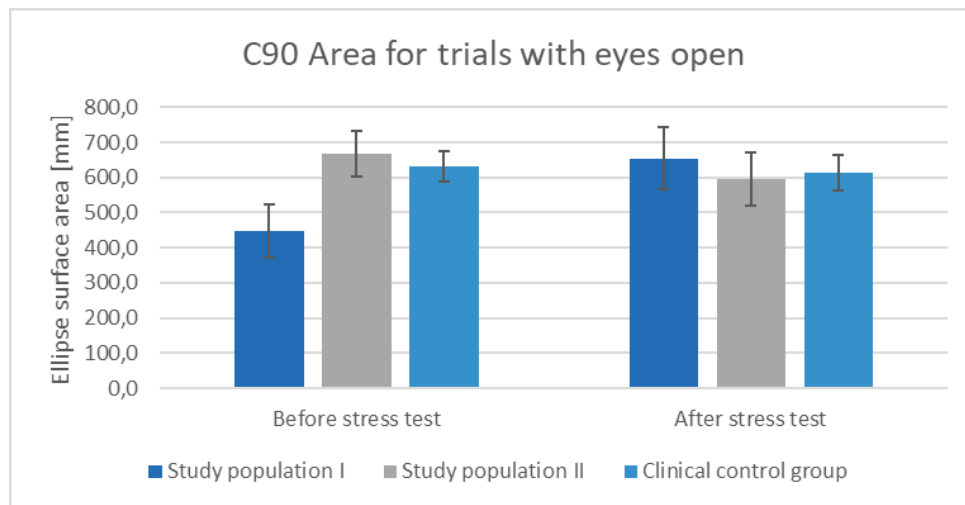The differences between groups in measurements taken before fatigue test ($F(2.45) = 2.83$; $p = 0.070$;

Fig. 3. Means and standard errors for ellipse surface area C90 Area in trials with eyes open in the control group, study population I and study population II

Table 5. Descriptive statistics for C90 Area in trials with eyes open

					95% CI	
		M	*SD*	*SE*	*LL*	*UL*
C90 Area O [mm²] – before fatigue test	Study population I	445.99	148.68	75.65	293.62	598.36
	Study population II	667.11	138.38	65.52	535.16	799.07
	Control Group	630.38	272.48	43.68	542.41	718.36
C90 Area O [mm²] – after fatigue test	Study population I	654.55	180.42	87.16	479.00	830.10
	Study population II	595.51	230.57	75.48	443.47	747.54
	Control Group	613.76	292.97	50.32	512.41	715.11

$\eta_p^2 = 0.11$) after fatigue test proved insignificant ($F(2.45) = 0.14$; $p = 0.874$; $\eta_p^2 = 0.01$). The results are illustrated in Fig. 3 and descriptive statistics is presented in Table 5.

Comparison of studied populations and the control group in respect of the ellipse surface area for trials with eyes closed (C90 Area Z)

In order to analyse the differences between groups in respect of C90 Area Z, we conducted analysis of variance in the mixed scheme 3×2 (study population I vs. study population II vs. control group; measurement: before vs. after fatigue test).

The conducted analysis revealed the significance of main effect for C90 Area Z, $F(1.45) = 6.79$; $p = 0.012$; $\eta_p^2 = 0.13$. The level of C90 Area Z before fatigue test ($M = 3480.81$; $SE = 356.58$) was lower than after fatigue test ($M = 5044.89$; $SE = 686.36$).

The main effect for the group proved to be significant, $F(2.45) = 5.24$; $p = 0.009$; $\eta_p^2 = 0.19$. Subjects from study population II ($M = 5338.49$; $SE = 799.22$) had higher levels of C90 Area Z in comparison with the control group ($M = 2493.15$; $SE = 565.14$; $p = 0.017$), whereas there were no differences between subjects from study population II and study population I ($M = 4956.92$; $SE = 960.55$; $p = 0.097$) or between study population I and control group ($p = 1.000$).

The interaction of both variables, the group and the measurement, proved significant, too $F(2.45) = 5.51$; $p = 0.007$; $\eta_p^2 = 0.20$. We did not find differences between measurements before and after fatigue test within the study population I ($F(1.45) = 0.01$; $p = 0.922$; $\eta_p^2 = 0.01$) and control group ($F(1.45) = 0.38$; $p = 0.542$; $\eta_p^2 = 0.01$). There were significant differences in the study population II ($F(1,45) = 17,25$; $p < 0,001$; $\eta_p^2 = 0,28$) – these subjects had higher C90 Area Z values in the measurements after fatigue test.

The differences between groups in measurements taken before fatigue test ($F(2.45) = 5.05$; $p = 0.011$; $\eta_p^2 = 0.18$) and after fatigue test ($F(2.45) = 5.39$; $p = 0.008$; $\eta_p^2 = 0.19$) proved significant. In measurements before fatigue test the subjects from study population I showed higher C90 Area Z levels than subjects from control group ($p = 0.008$). We did not record differences between study population II and study population I ($p = 0.188$) or between study population II and control group ($p = 0.017$). Subjects from study popu-
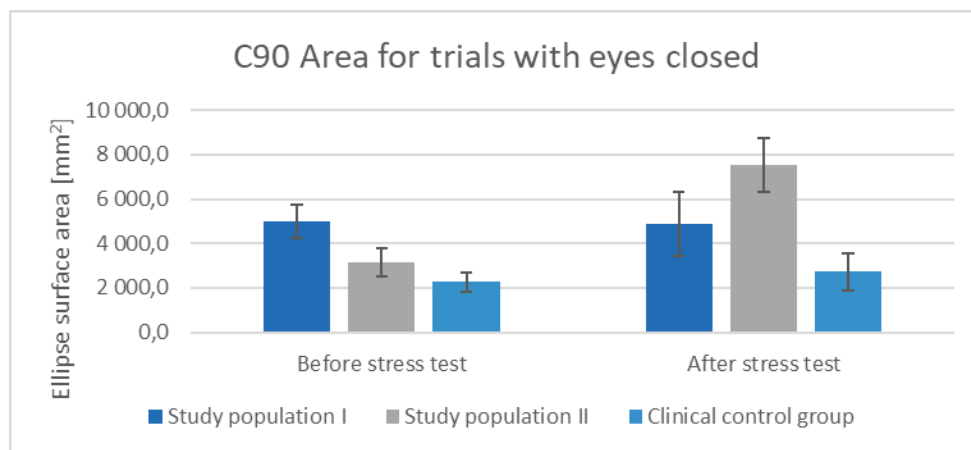

Fig. 4. Means and standard errors for ellipse surface area (C90 Area) in trials with eyes closed in the control group, study population I and study population II

Table 6. Descriptive statistics for ellipse surface area (C90 Area) in trials with eyes closed

		M	SD	SE	95% CI	
					LL	UL
C90 Area Z [mm²] – before fatigue test	Study population I	5018.99	4412.77	749.24	3509.95	6528.04
	Study population II	3158.38	1420.80	623.41	1902.77	9935.47
	Control Group	2265.06	1376.17	440.81	1377.21	4430.22
C90 Area Z [mm²] – after fatigue test	Study population I	4894.84	5025.50	1442.19	1990.12	7799.56
	Study population II	7518.60	6968.58	1199.97	5101.73	9935.47
	Control Group	2721.23	1517.70	848.51	1012.25	4430.22

lation had higher values of C90 Area Z after fatigue test than subjects from control group ($p = 0.006$). The differences between control group and study population I ($p = 0.602$), and differences between study population I and study population II ($p = 0.506$) proved insignificant. The results are illustrated in Fig. 4 and Table 6 presents descriptive statistics.

4. Discussion

The aims of the study were to assess static balance in subjects after unilateral and bilateral inversion injury who returned to sports activity they had had prior to the injury, so called "copers"; and also to assess the changes to static balance under fatigue in the studied groups.

We observed interesting differences in static stabilography tests between measurements before and after fatigue test, as well as in the qualitative analysis of landing. Study population I – with unilateral instability – had weakened mechanism of maintaining static balance in standing trials with eyes open and with eyed closed after fatigue test. Study population II – with bilateral instability – had weakened mechanism of maintaining static balance in single leg stance trials with eyed closed after fatigue test.

The single leg stance test in one of the most common tools used by clinicians to assess postural stability, particularly in athletes after inversion injury to lower extremity.

To prevent inversion injury in a foot's contact with the ground, the body has to detect the position and orientation of the foot towards the ground. This requires preparation, reflex and volitional control [10]. Inversion injuries often result from excessive plantar flexion, supination and internal rotation during the heel's contact with the ground [2]. This could point to weakened proprioception or neuromuscular control. While some authors report on sensory and movement deficits and joint position sense in subjects with CAI [15], others dismiss those reports [29], [30]. Involuntary muscle co-contraction seems to have equally important role in stabilizing joints in dynamic activities [9], [18]. Our present results are in line with the results published by Steib's team, which showed only slightly higher COP values during rest in the "copers" group in comparison with healthy subjects [24]. Similarly, Wikstrom et al. [28] did not find significant changes in COP levels with eyes open between "copers" and healthy controls. These studies suggest a degree of uncertainty as to the role of the discussed factors in recurring inversion injuries as well as to the justification of using static stabilography testing with eyes open for clinical assessment. Static stabilography with eyes open therefore seems to be a parameter of lower significance in subjects after inversion injury.

Another factor which impacts the risk of injury is the fatigue of the body [6],[25]. Fatigue results in generating decreased maximum voluntary contraction. It has been proved that in healthy adults with stable ankles fatigue decreases both passive and active sense of joint position. Fatigue is a factor predisposing to ankle inversion injuries even in healthy subjects. Adults with CAI show deficits in postural control under fatigue during single leg stance on the injured leg [8], [21], [23], [26], [27]. The results of our study also confirmed the impact of fatigue on static stabilography results in subjects after inversion injuries, i.e., "copers". Detailed analysis of stance trials with eyes open showed increase of COP trace length after fatigue test in study population I (with unilateral instability). We did not find differences in measurements before and after fatigue test in the control group or in the study population II. After fatigue test results of more than 73% of subjects were 1 – unsatisfactory or 2 – poor. "Copers" from study population II (with bilateral instability) had weakened mechanism of maintaining balance in static conditions with eyes open already before fatigue test. A total of approximately 68% had results of 1 – unsatisfactory or 2 – poor. Even though the results were not significantly different within this group after fatigue test, almost 50% of subjects had poor stability after fatigue test. In the control group, the results were on the 2 – poor or 3 – acceptable level (a total of 62.9% of subjects) before fatigue test, and there was a similar trend after fatigue test.

We drew some interesting conclusions from tests without visual control. We did not find differences in the levels of COP trace length Z (eyes closed) in the study population I and or the control group between the measurements before and after fatigue test. In comparison to the reference values, study population I had weakened mechanism of balance control in static conditions with eyes closed. Despite lack of differences after fatigue test the level of balance stayed on the same poor level. In the study population II (with bilateral instability), the effect was statistically significant – we found an increase in COP trace length values after fatigue test. This group's subjects had poor stability levels in relation to reference values, as 30% of the subjects had insufficient stability levels after fatigue test. These findings are in line with the findings published by Yaggie and McGregor [31]. Visual control deprivation leads to the sense of balance using information primarily from proprioception (distorted be-

cause of injury) from the locomotor system, as well as from the labyrinth. These can explain the poorer results in studied populations.

Studies on impact of fatigue use a variety of fatigue protocols with different criteria for reaching fatigue. It was crucial for our study to choose a fatigue protocol so that it reflected as much as possible the type of sports activity done in volleyball, football, or basketball, i.e., sports with the highest incidence of ankle injuries. Such fatigue protocol had to be based on interval training that engaged the muscles of lower extremities. It was important that the protocol include jumps or sudden changes of movement direction, i.e., activities typical for these sports disciplines. Of the protocols available in the literature, we decided to choose FAST-FP (Functional Agility Short-Term Fatigue Protocol) used by Cortes et al. [5]. This is a set of 4 different exercise types forming a single series. The number of series depended on subjects' individual endurance. Fatigue test was discontinued when the following criteria were met: subject did not reach a minimum of 90% of maximal height two consecutive exercise series, subject refused to continue exercise, subject had 90% of maximum heart rate. In each of the series subjects did three counter movement jumps to the height of a minimum of 90% maximum height; stepped up and down a stepper of a height of 30 cm for 30 s (the steady speed of the task of frequency of 1 Hz was timed with a metronome), five knee-bends (to the position of 90° bend at the knees) and proagility shuttle run 5 m-10 m-5 m. In the study by Cortes et al. [5], subjects completed a mean of 9.4 exercise series (±2.7), while, in our study, the subjects completed a mean of 12 series (±3.1). The mean time of fatigue test in our study was approximately 15 minutes. In most of the cases ($n = 46$) the test was discontinued because the subject refused to continue the exercise due to excessive fatigue; in 13 cases the subjects did not reach the height criterion of the jump, and in one case the test was discontinued because the subject felt pain in the chest.

The duration of the test also was important for the choice of the fatigue protocol. On the one hand, it was important to choose an experiment that involved the muscles of lower extremities, based on jumping ability, while on the other hand, uncertainty arose as to whether too quick fatigue protocols would be long enough to induce kinematic and kinetic changes after exercise. The study by Quammen et al. [22] provided an answer – its results showed that similar biomechanical changes to the lower extremities develop after a five-minute FAST-FP protocol and 45-minute SLOW-FP protocol. The Quammen et al.'s experiment analysed the effects of two different fatigue protocols and the risk of injury in patients after anterior cruciate ligament reconstruction. Using both the long oxygen protocol and the fast functional fatigue protocols showed that the lower extremity was under similar risk of injury under the conditions of fatigue and unexpected movement. Fatigue causes the decrease of flexion angle at the hips and knee and results in more upright body position, therefore resulting in increased anterior subluxation at the knee and extension of anterior cruciate ligament.

Limitations of the study

This study used fatigue protocol in which the number of series depended on subjects' individual endurance. Despite receiving considerable external motivation when doing the fatigue test, some of the subjects may not have put their maximum effort into the test, which may have affected the result of the study. Despite properly carried out the effect size (test power was 0.94, which proved that the studied sample was sufficient to conduct the analyses), the future research should be conducted on more participants in groups I and II.

The value of the conducted study

The study was conducted on a homogeneous study population with full medical documentation and verification of joint instability through medical imaging tests.

5. Conclusions

The incidence of structural ankle instability was not correlated with functional instability. Subjects with ankle instability, or "copers", had good functional levels, enabling them to perform sports activities. "Copers" had weakened proprioception in static stabilography tests. Short and intense fatigue protocol weakened the ability to maintain balance in static stabilography test with eyes closed.

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