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Postural stability of polish special forces operators

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The level of balance can play an essential role in a soldier's performance. For a Special Forces soldier, the footwear used or extra weight may be important factors affecting their balance level during combat operations or trainings. Therefore, the purpose of the study was to assess the level of static balance of Special Forces Operators and to determine the influence of select elements of a soldier's combat uniform and equipment on balance levels. The study group consisted of 37 Polish Special Forces Operators. To assess the level of static balance, the Romberg test was used in three variants (barefoot, with shoes, and with shoes, helmet, and vest). The measurements were made using the AMTI AccuGait portable force platform. The results of the analysis showed that the calculated average values of selected static balance parameters of soldiers differed depending on the variant of the Romberg test used, and in most cases, those differences were statistically significant ($\alpha < 0.05$). The lowest average values of parameters characterizing the level of static balance of Special Forces soldiers were calculated for barefoot measurements. The measurements with shoes and additional loads showed a statistically significant increase in almost all analysed parameters compared to barefoot measurements.

Keywords Soldiers, Static balance, External load

Balance is defined as the body's capacity to maintain its centre of mass, which corresponds to the position of its centre of gravity[1,2], and is the result of the interaction of the visual, somatosensory, and pre-limbic systems[3]. It is also defined as a dynamic process based on the sensory detection of movements and sensorimotor signals controlled by the central nervous system, which balances stabilizing and destabilizing forces[4] with the musculoskeletal system. By understanding the mechanisms that affect posture regulation, analysing these disorders can be crucial in various contexts connected with determining the level of risk or prevention against the loss of balance[1,5–7].

An optimal level of balance and postural stability is crucial in a soldier's profession. A low balance level can directly cause the risk of musculoskeletal injuries[8,9] and can increase the risk of falls[10]. Musculoskeletal injuries in soldiers can disrupt the training process, reduce combat readiness, and result in increased costs for injury rehabilitation. In addition, it can also be the reason for voluntary or involuntary dismissal from military service[9,11–13].

Many factors can affect the level of balance. Previous studies have analysed various aspects of balance in soldiers[14–17]. Boykin et al.[14] used the AMTI platform and the sharpened Romberg test to determine the correlation between balance level and age among 26 soldiers[14]. In another study, Palm et al.[15] used the Biodex Balance System to assess the effects of the visual and auditory systems on balance levels among a group of 23 soldiers, consisting of n = 11 males and n = 12 females.

The analysis of the level of balance using the AMTI platform was also performed on soldiers loaded with 20, 40, and 55 kg of equipment during the measurements, which was the exoskeleton load carriage assistive device of the lower limbs[16]. Funk et al.[17] assessed the effect of the proposed training program on the level of static and dynamic balance in Israeli soldiers (n = 27 male soldiers). Parameters such as average acceleration magnitude, root mean square acceleration, range, average frequency, and approximate entropy were measured using the inertial measurement unit (IMU) placed over the third lumbar vertebra.

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In other studies, the effect of exercise has been investigated[18], as well as physiological factors or muscular fatigue[8,10]. For example, during several months of training, Navy Seals are subjected to intense physical exertion, including marches and runs over long distances (up to 90 km), during which they are equipped with ceramic vests (7 kg), a rifle (4-5.5 kg), and an additional load of up to 40% of body weight[19].

The postural stability of soldiers can also depend on previous injuries[20] or other injuries such as visual disturbances[21] or mild traumatic brain injury, the consequences of which may include instability and sustained dizziness[22]. Mantua et al.[23] identified loss or insufficient sleep during training, in garrison, or during missions as factors that negatively affect balance levels.

In addition, the research on balance level conducted by DeBusk et al.[8] and Chander et al.[10] showed that it can also be impacted by the military footwear used during training and combat operations[8,10]. The weight of footwear[10] and the additional load of the 16 kg backpack were included in the study, and attention was paid to the level of soldiers' fatigue due to the duration of work[8]. Furthermore, Hill et al.[24] observed that tactical footwear used by soldiers is crucial for maintaining balance. The impact of different types of military footwear and a load of 27 ± 0.5 kg on a level of quasi-static balance was also studied by Fonseca et al.[25], who tested 12 soldiers, including two women.

In another study by Szczepańska et al.[26], a significant effect of additional load was observed on the postural stability of the participants by increasing the range of the COP sway during quiet standing. The relationship between the level of balance of soldiers performing a variety of training or combat tasks and the equipment with additional load was also noted by Funk et al.[17] and Heller et al.[27]. Heller et al.[27], who investigated the effect of carrying an 18.1 kg military backpack on the balance of 43 women, found that carrying an external load statistically significantly increased postural sway in the study group. A similar study on a group of soldiers with different loads was conducted by Schiffman et al.[28,29] and the authors analysed the effects of military clothing and equipment with a total weight of 6, 16, and 40 kg on postural sway. Both studies showed that increasing the external load and its positional change on the body increased the individual's body sway and the structure of the sway. In another study, Park et al.[30] investigated the effect of wearing a bulletproof vest with different load distributions (from 9 to 27 kg) on the level of static balance in a group of seven military college students. Their research showed that uneven weight distribution of the garment and load of a bulletproof vest affects the static balance of the body, e.g. increased sway of the center of plantar pressure.

Considering the cost of training Special Forces soldiers and the specificity of the tasks they perform carrying additional loads during missions, it may be essential to assess the level of balance, which low level may increase the risk of falls[10] or musculoskeletal injuries[8,9]. Thus, the aim of this study was to assess the level of static balance of Polish Special Forces Operators and to determine the influence of select elements of a soldier's combat clothing and equipment on it, as well as to analyse the effect of visual stimuli during measurements on the total level of body sway.

Material and methods

Sample

Participants in this study were 37 Polish Special Forces Operators aged between 27 and 51 years, who perform daily tasks in high-risk conditions, whether on exercises or in combat actions. The operations in the various combat teams can include the release of hostages from stationary facilities, the protection of specific objects and VIPs, reconnaissance, destructive actions at the deep rear and enemy's back, or combating terrorism at the interface of sea and land, as well as at naval facilities.

Methods

The subjects' body height was measured using a stadiometer (SECA 213 Hamburg, Germany). Body composition measurements were performed using the Tanita DC-430 S MA body composition analyser. A portable AMTI AccuGait force platform with dimensions of 50×50×4.4 cm was used to assess the level of static balance. The platform, placed on a hard and level surface, enabled measuring forces and moments of forces acting on it in three dimensions (Fx, Fy, Fz, Mx, My, and Mz). Data from the AMTI platform were collected and processed using the Noraxon MyoRESEARCH software MR3 (ver. 3.18.64) with an additional myoForce module. Based on the measured forces and moments of forces, the software calculated the position of the center of pressure (COP) parameter and its derivatives, i.e., COP 95% confidence ellipse area, COP length of the path, and average COP velocity, which were calculated based on COP displacements in the anterior-posterior (A-P) and medial-lateral (M-L) planes.

Design and procedures

Before the measurement, each respondent was informed about the purpose and course of the study. The measurements were started when the examined person understood all the instructions and reported readiness for the test. The test was performed in laboratory conditions. During the measurement, the subject and two researchers (the person performing the measurement and the person securing the subject) were in the room.

The Romberg test was used to assess the postural stability of soldiers. The subject stood on the force platform and took the measurement position: the feet were hip-width apart, and the arms rested loosely along the torso. During the measurement, the subject was asked to maintain a posture that was as stable as possible for 30 seconds. The measurement was first performed with eyes open (EO), during which the subject looked straight ahead at a point on the wall located 2 m from the platform and at eye level. After 30 seconds with EO, there was a 10-second break, and then the measurement was performed with the eyes closed (EC).

The Romberg test was performed using three measurement protocols: barefoot, in shoes, shoes and selected soldier equipment (a vest and a helmet) weighing a total of 7 kg (Figure 1). A 3-minute break was used between each measurement protocol. The entire measurement procedure was conducted always in the same order. One

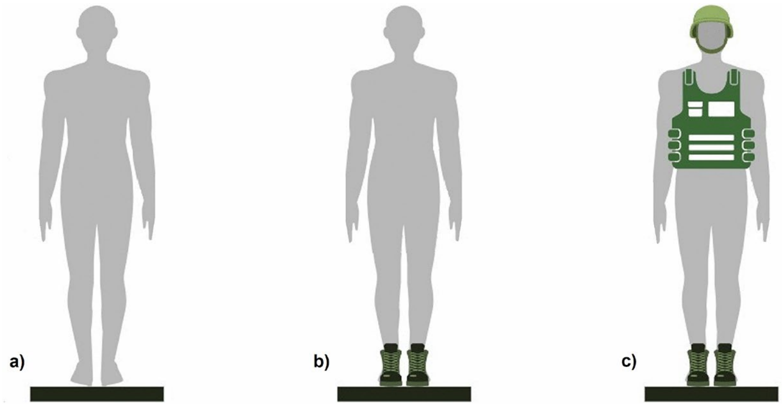

Fig. 1. Experimental set-up; (**a**) Barefoot; (**b**) Shoes; (**c**) Equipment.

measurement was performed in each case. During the measurement procedure, the subject was constantly secured by one of the researchers.

All protocols implemented in this study were approved by the Ethics Committee of the University of Rzeszów, Poland (resolution 2023/12/0060 of 6/12/2023), and were performed following the Declaration of Helsinki. Informed consent from participants was signed before data collection.

Statistical methods

To characterize the study group and to determine the level of static balance of Special Forces Operators, basic statistical measures were used, i.e., average, standard deviation, minimum and maximum values, median, and quartiles (Q1 and Q3). The normality of the distribution of the studied variables related to the assessment of the level of static balance was examined during the analyses using the Shapiro-Wilk test. Based on the obtained results, the non-parametric Wilcoxon test and the analysis of variance (ANOVA) in a repeated-measurement scheme (Friedman test) were used. Additionally, post hoc analysis was performed using pairwise comparisons (Durbin-Conover test). In the case of the multiple comparison test, the Bonferroni correction was included when determining the p-value. The effect size for the Friedman and Wilcoxon tests was calculated using:

- for the Friedman test[31]

$$W = \frac{\chi_w^2}{N(k-1)} \tag{1}$$

where: W – the Kendall's W test value; χ_w^2 – the Friedman test statistic value; N - sample size; k - the number of measurements per subject

- for the Wilcoxon test[31]

$$r = \frac{Z}{\sqrt{N}} \tag{2}$$

where: r – the effect size for Wilcoxon test; Z – standardized value for the Wilcoxon test; N – sample size

For measurements performed barefoot, in shoes, and in shoes with additional equipment, the Romberg coefficient (RR) values were determined. The RR value was calculated based on the formula[32–34]:

$$RR = \frac{EC - EO}{EC + EO} * 100\% \tag{3}$$

where: RR – Romberg's ratio; EC, EO – the result of an attempt with eyes closed or eyes open.

All statistical calculations were performed using the free software environment for statistical computing and graphics - R 4.3.1 programming language[35] at a significance level of α = 0.05.

Results

Table 1 summarizes the descriptive statistics for participants' age and body composition. Participants age ranged between 27 and 51 years ($\bar{x}$ = 37.0 ± 6.0 years). The average height and weight were 180.4 ± 5.5 cm and 85.1 ± 8.4 kg, respectively.

In the assessment of the static balance of the subjects, the parameters determined for the COP were considered, such as COP length of the path [mm][36], average COP velocity [mm/s][37] and COP 95% confidence ellipse area [mm^2], which determines the area of the ellipse containing 95% COP dispersion data[38]. The average level of static balance of Special Forces Operators, depending on the measurement protocol used is presented in

Variable	Unit	$\bar{x}$ ± Sd	Min.	Max.	Q1	Me	Q3
Age	years	37.00 ± 6.00	27.00	51.00	33.00	36.00	40.00
Height	cm	180.40 ± 5.45	171.00	193.00	176.00	181.00	183.00
Weight	kg	85.11 ± 8.43	71.20	104.70	78.50	84.10	90.10
BMI	–	26.10 ± 1.73	22.80	29.80	25.10	25.90	27.10
FAT%	%	18.99 ± 3.20	11.50	26.40	16.80	18.20	21.40
FAT	kg	16.33 ± 4.00	8.20	24.50	13.30	15.30	18.80
FFM	kg	68.77 ± 5.43	60.20	82.30	63.60	68.20	73.10
TBW	kg	47.75 ± 3.71	42.20	56.40	44.80	48.10	50.10

Table 1. Descriptive statistics for participants' age and body composition. $\bar{x}$ – mean; Sd – standard deviation; Min. – minimum; Max. – maximum; Q1, Q3 – the first and third quartile; Me – median; BMI – body mass index; FAT – body fat; FAT% – body fat percentage; FFM – fat free mass ; TBW – total body water

Protocol		Barefoot			Shoes			Equipment				
Parameter		$\bar{x}$ ± Sd	p	e.s.	$\bar{x}$ ± Sd	p	e.s.	$\bar{x}$ ± Sd	p	e.s.	p_{fr}	e.s.
Ellipse [mm^2]	EO	136.68±95.35	0.2174	-0.20	178.11±108.17	0.1090	-0.26	200.92±140.35	0.1496	-0.24	0.0091*	0.13
	EC	118.35±69.46			161.41±100.76			172.08±120.46			0.0188*	0.11
Path [mm]	EO	182.57±70.81	$< 0.0001^*$	0.71	209.70±83.80	$< 0.0001^*$	0.82	238.43±93.72	$< 0.0001^*$	0.79	$< 0.0001^*$	0.30
	EC	243.43±112.36			308.38±140.15			332.70±133.21			$< 0.0001^*$	0.38
Velocity [mm/s]	EO	6.16±2.49	$< 0.0001^*$	0.69	7.03 ± 2.77	$< 0.0001^*$	0.81	7.89±3.13	$< 0.0001^*$	0.77	$< 0.0001^*$	0.30
	EC	8.16±3.79			10.22±4.69			11.03±4.38			$< 0.0001^*$	0.38

Table 2. The level of static balance of Special Forces Operators according to the different conditions assessed. $\bar{x}$ – mean; Sd – standard deviation; EO – eyes open; EC – eyes closed; p_w – probability of Wilcoxon test; p_{fr} – probability of Friedman test; e.s. – effect size; Ellipse – COP 95% confidence ellipse area; Path – length of the COP path; Velocity – average COP velocity; * – statistical significance.

Table 2. In the barefoot measurements, higher values of the COP 95% confidence ellipse area were delineated in the EO sample, where the average value, in this case, was 136.68 mm^2 and the difference from EC (118.35 mm^2) was not statistically significant (p > α). In contrast, statistically significant differences in average values were determined for the parameters of COP path length.

Considering the protocol in which the participant stood on the platform wearing footwear (Table 2), the average values in all three determined parameters and variants (EO, EC) were higher compared to the protocol described above. Moreover, in the ellipse area, the results in EO and EC tests were at comparable levels (p > α) and as before (barefoot measurement), during the EC measurement, the area was smaller (161.41 mm^2) than during the EO measurement (178.11 mm^2). Referring to the COP path length and COP velocity of the tested soldiers, lower average values were calculated for the EO test (Table 2). In addition, the results of the Wilcoxon test show statistically significant differences between the results obtained during EO and EC measurements for both parameters.

In another measurement protocol, soldiers wore a vest and a helmet, and the measured values of the tested parameters were at the highest average levels (Table 2). In the two analysed parameters, (i.e., COP path length and COP velocity), the calculated values were statistically significantly differentiated by the type of test made (EO and EC). For the length of the COP path, the higher average value was determined in the EC test at 332.70 mm during the 30-second measurement. In addition, the parameter determining the average speed of the COP point was calculated at a higher level for the EC variant (11.03 mm/s). The analysis of the parameter 95% confidence ellipse area for the protocol under study showed (as in the barefoot and shoes protocols described above) that the larger area of the ellipse was obtained by the soldiers in the EO test (200.92 mm^2). The difference between the averages calculated in the two tests (EO and EC) was 28.94 mm^2 and was not statistically significant (p = 0.1496).

The analysis of the static balance level of Special Forces Operators also included the effect of footwear, vest, and helmet on the studied parameters. To check whether the results obtained in the Romberg test differed statistically significantly depending on the protocol, the Friedman test was used (Table 2), followed by a Durbin-Conover post hoc test with Bonferroni correction (Table 3). Based on the results of the Friedman test, it was observed that in all three studied parameters (COP 95% confidence ellipse area, COP path length, and COP velocity), there were statistically significant differences in each of the Romberg tests (EO and EC) ($p_{fr} < 0.05$). In addition, the value of the calculated effect (e.s.) was the highest and reached e.s. = 0.38 in the parameters of COP path length and COP velocity for tests with eyes closed.

Post hoc test results for the EO test in the COP 95% parameter confidence ellipse area showed statistically significant differences between the barefoot and shoe measurement protocols (p = 0.041), as well as in a vest and helmet (p = 0.011). Similar results were also obtained for comparisons in the EC test, showing significant variation in levels of COP 95% confidence ellipse area between the mentioned protocols. Considering the results

Parameter	Protocol	EO		EC	
		Shoes	Equipment	Shoes	Equipment
Ellipse	Barefoot	0.041*	0.011*	0.039*	0.039*
	Shoes	—	1.000	—	1.000
Path	Barefoot	0.176	$< 0.001^*$	$< 0.001^*$	$< 0.001^*$
	Shoes	—	0.002*	—	0.740
Velocity	Barefoot	0.026*	$< 0.001^*$	$< 0.001^*$	$< 0.001^*$
	Shoes	—	0.014*	—	0.230

Table 3. Results of Durbin-Conover post-hoc test with Bonferroni correction. EO – eyes open; EC – eyes closed; * - statistical significance;Ellipse – COP 95% confidence ellipse area; Path – length of the COP path; Velocity – average COP velocity.

Romberg ratio	Barefoot				Shoes				Equipment			
	$\bar{x}$	Sd	Min.	Max.	$\bar{x}$	Sd	Min.	Max.	$\bar{x}$	Sd	Min.	Max.
RR Ellipse [%]	-6.27	29.55	-61.62	56.27	-5.89	22.19	-55.56	40.00	-9.19	24.41	-51.96	30.92
RR Path [%]	12.69	13.13	-11.76	42.60	17.44	12.02	-19.55	39.77	15.70	13.01	-12.09	39.05
RR Velocity [%]	12.79	13.73	-11.11	46.67	16.72	11.92	-16.67	40.00	15.82	13.67	-16.67	41.67

Table 4. The Romberg ratio. $\bar{x}$ – mean; Sd – standard deviation; Min. – minimum; Max. – maximum; RR – Romberg ratio; Ellipse – 95% confidence ellipse area; Path – length of the COP path; Velocity – average COP velocity.

of the Durbin-Conover post hoc test in the COP path length parameter, in the EO test, statistically significant differences were found between measurements taken with a helmet and vest, with shoes (p = 0.002), and without shoes ($p < 0.001$). In Romberg's EC test, significantly different COP path length results were found between the barefoot protocol and the other types of measurements ($p < \alpha$). Non-significant differences were determined between the results of the boot test and the additional load with the helmet and vest. The last parameter tested for differences due to the protocol type used was COP velocity. In trials performed with EO between all protocols, statistically significant differences in COP velocity levels were determined. In the tests conducted with EC, significant differences were found between measurements taken barefoot and those taken with shoes and then with a helmet and vest. In both tests, the probability value of the Durbin-Conover post hoc test was less than 0.001.

To identify the effect of vision on the participants' balance level, Romberg coefficient values were calculated and are displayed in Table 4 and Figure 2. The lowest average values were calculated for the ellipse area parameter for the measurement in shoes (RR ellipse = -5.89%), which were also negative. The highest Romberg coefficient values were characterized by the path and velocity parameters for the shoe protocol. The average values of Romberg coefficients were 17.44% for COP path length and 16.72% for COP velocity.

Discussion

The aim of the study was to assess the level of static balance of Polish Special Forces Operators, and to analyse how the equipment used, such as a helmet and vest, affects its parameters during the Romberg test. In addition, the effect of vision (eyes open – EO condition versus eyes closed – EC condition) on the soldiers' level of postural stability during the tests was also studied. An analysis of the average values of selected balance parameters, including COP 95% confidence ellipse area, COP path length, and COP velocity measured during each Romberg test (EO and EC), showed significant statistical differences between the different measurement protocols.

Comparing the results of the barefoot and shoe trials, there was an increase of 30.31% in the COP 95% confidence ellipse area parameter observed after wearing shoes for the EO condition. An increase of nearly 36.38% was also observed in the EC condition. In the case of an analysis of the COP path length and COP velocity parameters, the wearing of footwear also caused an increase in the average values of 14.86% in EO and, 26.68% in EC (COP path length) trials, and 14.12% in EO and 25.25% in EC (COP velocity) trials, respectively. It is worth noting that the increase for EC trials of the COP path length parameter was almost 12%, and COP velocity was 11% compared to the results achieved with EO. The analysis of the postural stability of Special Forces Operators in protocols on barefoot and shoes also showed statistically significant differences between the EO and EC attempt in the COP path length and COP velocity parameters.

The impact of different types of military footwear (standard tactical footwear and lightweight tactical boots) on postural stability in soldiers was noted by Chander et al.[10]. The authors concluded that to avoid potential falls and the consequent injuries, a soldier needs to use properly designed footwear that minimizes the impact of physiological fatigue and improves balance. DeBusk et al.[8] also observed that the type of footwear used by soldiers statistically significantly differentiated their level of static balance. Participants of this study obtained significantly greater average values for COP 95% confidence ellipse area, postural sway displacement in the

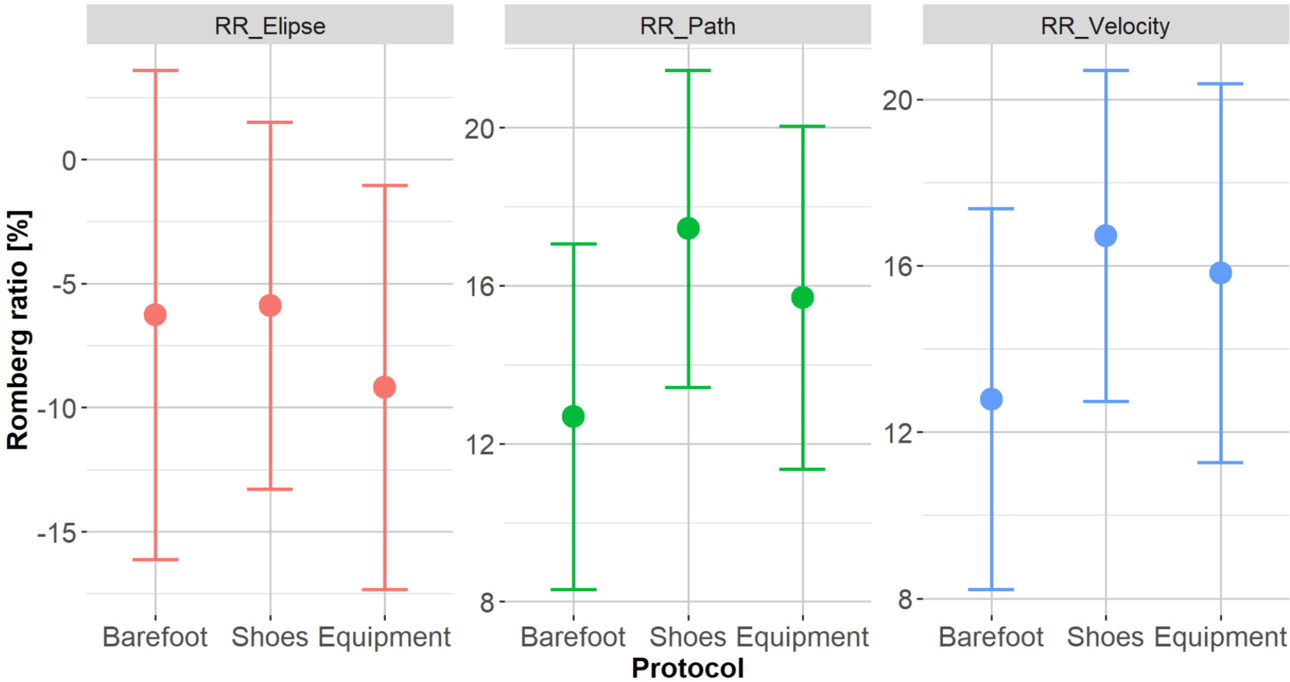

Fig. 2. The confidence interval (95%) and the mean value of the Romberg ratio [%] for different trials.

medial-lateral directions (EC), and anterior-posterior and medial-lateral postural root mean square sway (EO) while wearing standard tactical footwear compared with minimalist military-type tactical boot.

By comparing the tests with shoes and with an additional load of 7 kg (helmet and vest), an increase in all parameters of 14% (COP path length), 13% (95% confidence ellipse area), and 12% (COP velocity) was observed for the EO condition. Analysis for the EC tests showed that the observed increase for the studied parameters was lower (COP velocity of 8%, 95% confidence ellipse area of 7%, and COP path length of 5%). According to the percentages determined between the barefoot measurement protocol and the one with the additional load, the highest increases were observed for the parameter 95% confidence ellipse area, where the average increase in ellipse area was 47% for the trial with the EO, and 45.40% for the trial with the EC. With the soldiers wearing the helmet and vest for both tests (EO and EC), percentage increases in parameters were also calculated for COP path length (30.60% in the EO test and 36.67% for EC) and COP velocity (28.08% for EO and 35.17% for EC). Qu and Nussbaum[39] analysed the effect of additional load on COP parameter velocity using loads of 10% and 20% of the participant's body weight (distributed in two load packs, placed dorsally and ventrally) on 12 young, healthy participants, and calculated a maximum increase in the COP velocity parameter of 8.1%. In another study, Szczepańska et al.[26] observed an increase in COP movement speed of 35% for an additional load of 7 kg (placed in the load-vest) in a studied group of 30 healthy, untrained physical education students in comparison to the no-load protocol.

In the research of Schifmann et al.[28], the effect of different variants of loads of soldiers on postural sway (i.e., 6 kg load items plus a helmet, an armour vest, and a cloth vest with pouches on the front) was analysed, and this group found that the ability to maintain a stable posture is significantly affected by external loading. With increasing load, the values of the parameters also increased linearly for the lengths of COP excursions, planar motion, and the boundary area of the COP excursions. Wearing basic combat equipment weighing 16 kg (a helmet, an armour vest, and a cloth vest with pouches) also cause unfavourable changes in balance for the soldier compared to an unloaded measurement[29]. In another study by Schifmann et al.[16], also taking postural sway assessment and an additional load of 20 kg (including a weighted vest, helmet, and M4 rifle) into account, 40 and 55 kg emergency approach march loads showed that with the increase of load, there was an increase in the values of the maximum range of movement in the A-P and the M-L direction, A-P excursion length, planar motion, and total sway area. Limitations and unfavourable changes in the efficiency, mobility, and postural control of soldiers were identified by Loverro et al.[40] because of the full coverage IOTV with all plates and the additional combat load added to the vest. In the study, changes in the analysed parameters between no armour and full armour coverage, and different configurations of body armour protection levels with additional equipment of fighting load carriers were observed. It is worth noting that not only the weight of the load carrier, but also its location, affects postural sway[29]. A similar conclusion was also formulated by Park et al.[30].

During military training or combat missions, soldiers, in addition to their helmets, vests, weapons, and ammunition, carry essential equipment on their backs[40]. Heller et al.[27], who studied the effect of additional loading on balance, observed that the applied load of a military backpack weighing 18.1 kg statistically significantly differentiated the average values of the analysed parameters - COP path length, M-L excursion, A-P excursion, and COP area. Chander[10] concluded that the decrease in postural stability (balance) and appropriate footwear could also be influenced by muscle fatigue or muscle effort due to physiological workload, based on measurements with an additional load (16 kg rucksack). In another study, Fonseca et al.[25] also observed that the additional load of soldiers (about 27 kg) carried in a backpack caused a statistically significant increase in all analysed static balance parameters. Similar conclusions were formulated by May et al.[41] regarding the impact of a backpack with a load on balance and situational awareness. Heller et al.[27] also noted that the increased swing of the centre of gravity caused by the additional load increases the risk of falls or injuries. Larger body swings while standing can lead the centre of body mass to the limit of the support area, which leads to lower body stability, and consequently, can lead to loss of balance[28,42]. Schiffman et al.[28] also proved that the increase in load required the soldier to have better muscular control.

To maintain a stable posture, the human cardiovascular system constantly processes signals received from the vestibular apparatus, the organ of vision and proprioceptive receptors[15,33,43]. The Romberg coefficient was calculated to investigate the influence of the mentioned systems on the balance level of soldiers. Higher values of the Romberg coefficient (formula 1) show more postural instability. Positive values mean more stability in the EO, and negative values in the EC tests. The calculated negative values of the coefficient for the 95% confidence ellipse area showed that the visual information obtained during the test was less significant for this parameter. In the current study, the results obtained in the EO, and the EC tests did not differ statistically significantly in any of the measurement protocols. For the parameters COP length and COP velocity, the values of the Romberg coefficient were set at a positive level, which can indicate a more important role of the sense of vision in the speed of postural stabilization of soldiers. As shown by Nagano et al.[44], the postural stability of soldiers (without additional load) was significantly affected by visual signals recorded during the measurements. Statistically significant differences were determined for all the parameters analysed, except for the average M-L and A-P COP position, and postural stability was lower in the EC test.

Postural stability controlled by the central nervous system depends not only on the type of stimuli received from the vestibular, somatosensory, or visual systems, but also on each individual's capacity to process information of this type[15]. Moreover, damage to the receptors, defective flow of information from the receptors to the central nervous system, or poor interpretation of the signals received can cause abnormalities in postural stability[45]. The results of the current study indicate that the static balance of the studied group of Special Forces soldiers is significantly affected by used shoes and an external load such as a helmet and vest. Therefore, it seems reasonable to include in future research a more extensive amount of additional equipment that soldiers wear in realistic combat conditions. Furthermore, to minimise the negative impact of tactical equipment on the level of postural stability of soldiers, consideration should be given to how it is attached to the body.

Limitations

To assess the level of balance of Special Forces Operators, the structure of footwear they use during training, exercises, and combat missions should be considered[8,10,46]. Additional factors that significantly affect the level of postural stability are muscle fatigue, skeletal muscle weakness, or injuries[10,20,47]. As was also observed in various studies, the balance level of the subjects also depends on body weight and its normal level[3,48–52], age[14,53], physical fitness[18] and the amount of sleep[54]. Additionally, the conducted measurement procedure wasn't counterbalanced or randomized. These are the aspects that were not included in the present paper, thereby constituting its limits.

Conclusions

Based on the research, it was concluded that the lowest average values of the parameters 95% confidence ellipse area, COP path length, and COP velocity for the Romberg test were determined for barefoot measurements. It was also found that the soldiers' athletic footwear did not positively affect their level of static balance. The average increase in the values of the tested parameters compared to the barefoot measurements showed statistical significance, except for COP path length for EO. Furthermore, the additional load of a vest and helmet negatively affected the soldiers' level of static balance. The increase of average values in the examined parameters 95% confidence ellipse area, COP path length, and COP velocity concerning the barefoot measurement was statistically significant in both the EO and EC tests. Finally, analysis of the Romberg coefficient among Special Forces Operators, especially for parameters characterizing the path length of COP displacement and average velocity of COP displacement, suggests that visual information can play an essential role in the speed of their posture stabilization. However, this type of information was not crucial for the parameter 95% confidence ellipse area.

Data availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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Declarations

Competing interests

The authors declare no competing interests.

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