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Postural stability pattern as an important safety factor of firefighters

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Abstract.
BACKGROUND: Firefighting is a hazardous profession that involves high fall risk and is crucial component for the safety of people.
OBJECTIVE: The aim of this study was to identify factors that impact on postural stability patterns of firefighters.
METHODS: The study examined 177 Polish firefighters from the National Firefighting and Rescue System (NFRS) aged 31.9 ± 10.1 years, with body height of 179.6 ± 5.93, body mass of 83.9 ± 11.0 and BMI of 26.0 ± 3.03. Postural stability was evaluated by means of the Balance System SD (Biodex USA) set at the level 12 of instability, in a sportswear, bunker gear, with and without visual input. The fall risk test (FRI) was also performed. Four indices were analysed: overall stability index (OSI), anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and fall risk index (FRI).
RESULTS: Mean results for fall risk index (FRI) were in the normal range for all age groups regardless of the type of clothing the firefighters were wearing. Individual results obtained in the fall risk test, 128 firefighters were in the normal range for their age, furthermore, 10 firefighters obtained better results than the normal range, 34 firefighters had worse results and 5 people failed to complete the test. Postural stability with eyes closed was found to decline with age. Wearing bunker gear did not have an effect on postural stability.
CONCLUSIONS: Balance tests should be integrated into the firefighting training routines in order to improve balance and support fall prevention. Exercises with reduced visual input should also be incorporated into the training methodology.

Keywords: Work safety, firefighters' balance, fall risk test

1. Introduction

Firefighting is an integral component in organization of homeland security of any country. The major focus of firefighting policies is on prediction, recognition and extinguishing fires, combating natural disasters or local hazards, operations to prevent chemical, ecological and technological disasters, water and mountain rescue operations as well as search and rescue operations [1]. Firefighting is a hazardous profession that involves high fall risks. In firefighting and rescuing operations, firefighters are exposed to a varied, complex, unpredictable, and rapidly changing environment. They frequently work on roofs and ladders. Walking surfaces are often cluttered or slippery because of the existence of debris, building materials, and contaminants [2]. On average 30,289 American firefighters are injured during emergencies every year, nearly 11% being due to falls [3]. Many aspects of the firefighters' job may adversely impact their postural stability and potentially increase the risk of falling. For instance, prolonged work shifts may be an important contributor to the high prevalence of slips and falls among firefighters [4]. The balance demands of work and deterioration with age should be taken into account when work ability is

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promoted, especially among older workers in physically demanding jobs [5].

During fire emergencies, firefighters wear personal protective clothing (PC), composed of layered thermal protective clothing (flame resistant outer shell and insulating thermal liner), heavy footwear and helmets, and often use self-contained breathing apparatus (SCBA) [6]. Although PC and SCBAs may offer a good barrier for the firefighters from thermal radiation, burns, injuries, smoke and noxious gases, they can have negative effects on gait, metabolic and thermal efficiency and fatigue, leading to a significant reduction in work capability and work duration [6–9]. There are various types [7] of protective clothing (PC), characterized by different features and, consequently, different overall weight of the equipment [10]. In Poland protective clothing weighs about 12 kg (ankle boots with thick-soles, firefighter clothes, helmet, belt, flashlight) [11]. Jacket and pants should not weight more than 3.8 kg [12]. In other countries PC weight ranges from 8.2 kg to 9.8 kg [13]. Moreover, if SCBA is used it adds on average 11 kg of extra weight [10, 13]. So all the equipment weighs about 20 kg.

It is worth noting that firefighters expect that the next generation of personal protective equipment should offer features, which would have a positive impact on their professional health, including postural stability control [12]. Their expectations concerning the new generation of protective clothing include wireless communication stations, location tracking systems, automated body cooling systems, solutions to support vision, hand-free lighting systems and air and object temperature monitoring systems [14].

Adequate postural stability control is substantially impaired by hard conditions of firefighting operations, extended time of emergency and the rescuer's level of fatigue [15]. In the absence of vision [eyes closed], the self-contained breathing apparatus (SCBA) reduces anterior-posterior stability (APSI) while the use of heavier equipment is likely to increase fall risk during emergencies [16]. Too heavy footwear, low flexibility of the outsole and a long time of wearing footwear have a negative effect on the ability to maintain balance under conditions typical of firefighting emergencies [17]. Weight of bunker gear and its condition [clothing drenched during the rescue operation] modifies postural stability and substantially reduces the firefighter's mobility [18]. To date, it is unclear whether thermal protective clothing and a self-contained breathing apparatus (TPC/SCBA) worn by firefighters impairs balance, and, if so, whether this is due to the added equipment weight, reduced visual input, or a combination of factors. It is also likely that other intrinsic and extrinsic factors related to the firefighter's health and fitness influence the TPC performance [19].

It is known that postural stability is maintained, controlled, and monitored by a complex system, consisting of the vestibular organs, the visual organs, proprioception, touch and pressure [20]. This system is critical to a safety during firefighters' vocational activities [11]. However, the factors which have the strongest impact on losing postural control need to be explained in order to minimize these causes.

The aim of this study was to recognize factors like age, equipment and visual conditions that influence postural stability among firefighters. This information will help develop optimal solutions for the safety systems used during standard rescue activities, reduce fall risk and provide basis for the integration of adequate prevention exercises into the firefighting training routines to improve postural stability.

2. Material and methods

2.1. Participants

The study examined 177 Polish, professional firefighters aged 31.9 ± 10.1 years, with body height of 179.6cm $\pm$ 5.93, body mass of 83.9kg $\pm$ 11.0 and BMI of 26.0 ± 3.03. Participants were professional firefighters that graduated from The Polish Main School of Fire Service and that was their only job. Experience is proportional to their age. Research was performed in early hours at Józef Piłsudski University of Physical Education in Warsaw between years 2016 and 2017. In the next part of the analysis, firefighters were divided into three age groups, with the first group including people aged 19 to 24.9 years, the second including those aged 25 to 43.9 years and the third – firefighters aged 44 to 60 years (Table 1).

There were no differences of statistical significance in body mass and height, between those groups.

Table 1
Participants' anthropometrics (mean $\pm$ SD)

Group	N	Age (years)	Body height (cm)	Body mass (kg)
Male 1	74	21.8 ± 1.44	180.0 ± 6.67	79.9 ± 8.21
Male 2	79	37.1 ± 5.40	178.8 ± 5.20	85.8 ± 10.33
Male 3	24	46.9 ± 2.37	178.6 ± 5.58	91.1 ± 14.99

All the participants with no history of falls with serious consequences underwent medical examinations in order to exclude previous injuries and diseases that would have reduced function of the vestibular system. The results of the examinations were used to qualify them for laboratory tests of postural balance. The exclusion criterion was a positive result of one of the following tests [21]: cerebellar testing (finger-to-nose test, diadochokinesis, pronator drift test) and the results of static and dynamic tests which assess the correctness of posture and gait (Romberg's test, Unterberger's test, the Babinski-Weil test, the Fukada test, the straight line test). The inclusion criteria were written consent to participate in the examination, being an adult and professionally active firefighter.

The approval was obtained from the Ethical Committee of Military Institute of Aviation Medicine in Warsaw and additional informed consent was obtained from all participants for whom identifying information is included in this article.

2.2. Data analysis

The research methodology included taking a complete medical history and examination that excluded injuries or diseases of the vestibular system, anthropometric measurements, postural stability tests using Biodex Balance System SD (BBS) platform (Shirley, NY, USA) with an unstable ground. Two testing protocols were used: in sportswear and in bunker gear (dedicated clothing, including helmets but without face masks and air cylinders). The tests were composed of three 20-second attempts with 10-second breaks between each other. Postural stability test (PST) and fall risk test (FRT) were performed [22]. PST was performed twice in different conditions of visual input. The twelfth level of platform instability was set during the test. FRT is a fall risk test performed with eyes open, with platform instability varying from the level 6 to level 2. The measurements in the presence of vision were performed with the feedback provided during both tests. Fall risk test and the standards were developed based on the research conducted in the University of Dayton, Ohio, USA [23]. Each test was performed in standing on both legs. Feet position on the platform was unchanged for all tests. Four stability indexes were analysed [22]: overall stability index, given as $\mathrm{OSI} = \sqrt{\frac{\sum [0-x]^2 + \sum [0-y]^2}{\#\text{samples}}}$, anterior/posterior stability index, medial/lateral stability index and fall risk index. High level of postural stability index means substantial displacements of the center of pressure (CoP) that reflect problems with maintaining balance of the person examined.

2.3. Statistical analysis

Satistical analysis procedure was carried out with use of the Statistica 12.5 software [24]. The parameters analysed in the study were tested for normal distribution using the Shapiro-Wilk test. Each parameter was described using descriptive statistics [means and standard deviations] and next a multiple factor ANOVA was performed, with stability parameters being dependent variables whereas the measurements and tests [age, clothing, eyes open and closed] represented independent variables. Statistical significance of differences was evaluated by means of the *post hoc* HSD Tukey test [24]. The effects and interactions between variables were verified using the ANOVA test for main effects and factorial designs. Statistical significance was set at the customary level of $p \leq 0.05$ for all analyses.

3. Results and discussion

3.1. Results

Mean results (Table 2) for fall risk index (FRI) were in the normal range for all age groups regardless of the type of clothing the firefighters were wearing.

Table 2
Fall risk indexes ($\bar{x} \pm SD$) for eyes open in the first, second and third age groups

Age groups	I		II		III	
Type of clothing	Sportswear	Bunker gear	Sportswear	Bunker gear	Sportswear	Bunker gear
FRI(6-2) EO	$1.44 \pm 0.69^{1,2}$	$1.51 \pm 0.70^{4,5}$	$2.13 \pm 1.13^{1,3}$	$2.16 \pm 1.18^{4,6}$	$2.95 \pm 1.46^{2,3}$	$3.06 \pm 1.39^{5,6}$
Standard FRI EO	1.00–2.3		1.2–3.0		1.3–3.33	

Footnotes: FRI – fall risk index 6-2, EO – eyes open. Examination I – in sportswear, Examination II – in special bunker gear (uniform). Standard – Biodex, Version 3.1; Biodex Medical Systems (22). Statistical significance of differences: ^{1}-$p = 0.000096$, ^{2}-$p = 0.000022$, ^{3}-$p = 0.0027$, ^{4}-$p = 0.000339$, ^{5}-$p = 0.000022$, ^{6}-$p = 0.000845$.

The FRI deviations tended to increase with age. The ANOVA analysis revealed the effect of the age factor $F(2, 340) = 42.375$, $p = 0.0001$. Mean results of the firefighters from the National Firefighting and Rescue System (NFRS) wearing bunker gear were lower than in the case of the sportswear. However, no effect of clothing and age/clothing interactions was found in any group.

Considering the individual results obtained by the firefighters in the fall risk test, 128 firefighters were in the normal range for their age, with mean values of 1.52 ± 0.5. Furthermore, 10 firefighters obtained better results (mean 0.69 ± 0.17), 34 firefighters had the results worse than the normal range (3.83 ± 0.82) and 5 people failed to complete the test as it was too difficult for them.

It is worth noting that the people whose results fell outside the normal range had also the highest differences between the indexes for eyes closed and eyes open, see Table 3. Contribution of vision to compensation of balance disturbances was substantial in this group, with 3.59, 2.26 and 2.21, respectively. Furthermore, 5 people did not complete the test with eyes closed at the level 12 of platform instability as they were unable to complete the test.

Analysis of the results of the postural stability test across age groups revealed statistically significant differences (See Fig. 1) between age groups in the absence of vision. Stability indexes increase with age. With visual input, no significant decline in stability was observed for overall, anterior-posterior and medial-lateral indices except for FRI.

Test of main effects in ANOVA revealed a significant impact of the vision factor on the mean value of the analysed parameter and an insignificant group effect (Fig. 1). However, no differences were found between the results in sportswear and bunker gear. A substantial sensitivity to exclusion of visual information was found in three groups.

The *post hoc* Tukey test for the parameters evaluated in the bunker gear revealed differences between the first and second groups (OSI $p = 0{,}0121$, APSI $p = 0{,}0447$) and between the first and third groups (OSI $p = 0{,}0077$, MLSI $p = 0{,}00043$). However, the groups 2 and 3 did not differ between each other in postural stability indices (OSI, APSI and MLSI).

3.2. Discussion

Identifying issues with firefighters' stability can help improving safety and is fundamental for preventing falls and injuries. The factors that affect fall risk in professionally, active firefighters include internal factors like balance, age, experience, muscle strength, physical fitness, body mass and external factors, such as customized bunker gear, reduced visual input, condition of the surface and temperature [25]. Injuries in a firefighters' workplace can be predicted by baseline measures of musculoskeletal movement and physiology [26].

In our study, we performed the test on the BBS platform at variable platform instability, the fall risk test, with stability reducing from the level 6 to 2. The results of the fall risk test (FRT) obtained for the measurements in bunker gear and sportswear were in the normal range in 128 firefighters. However, the reduction of postural balance was greater but statistically insignificant in the bunker gear. Ten people had results above the norm, whereas 39 firefighters (22%) had challenges with postural balance and obtained the results below the norm, which is an important finding as they are substantially exposed to injuries [11]. Firefighting is a dangerous job with high fall risk [27]. Firefighters in action wear a customized bunker gear, which can affect one's stability especially when it's heavy. Moreover, there are many kinds of bunker gear, characterized by different equipment that differs in weight [28]. This study demonstrated that special protective clothing did not impair balance, which may have resulted from the fact that the participants were examined without SCBAs and face masks, that weighs on average 11 kg. The components of the bunker gear that have the biggest effect on deterioration of postural stability include panorama full-face

Table 3
Differences in indexes depending on the FRI norm and visual input

Index	N	Difference OSI 12 CE/ OSI 12 OE	Difference APSI 12 CE/ APSI 12 OE	Difference MLSI 12 CE/ MLSI 12OE
Standard	128	1.80 ± 1.07	1.15 ± 0.72	1.14 ± 0.75
Below the standard	10	1.14 ± 0.19	0.69 ± 0.25	0.67 ± 0.37
Above the standard	34	3.59 ± 2.40	2.26 ± 1.49	2.21 ± 1.65

Footnotes: OSI – overall stability index, APSI – anterior/posterior stability index, MLSI – medial/lateral stability index, 12 – dynamic balance level 12, EO – eyes open, EC – eyes closed.

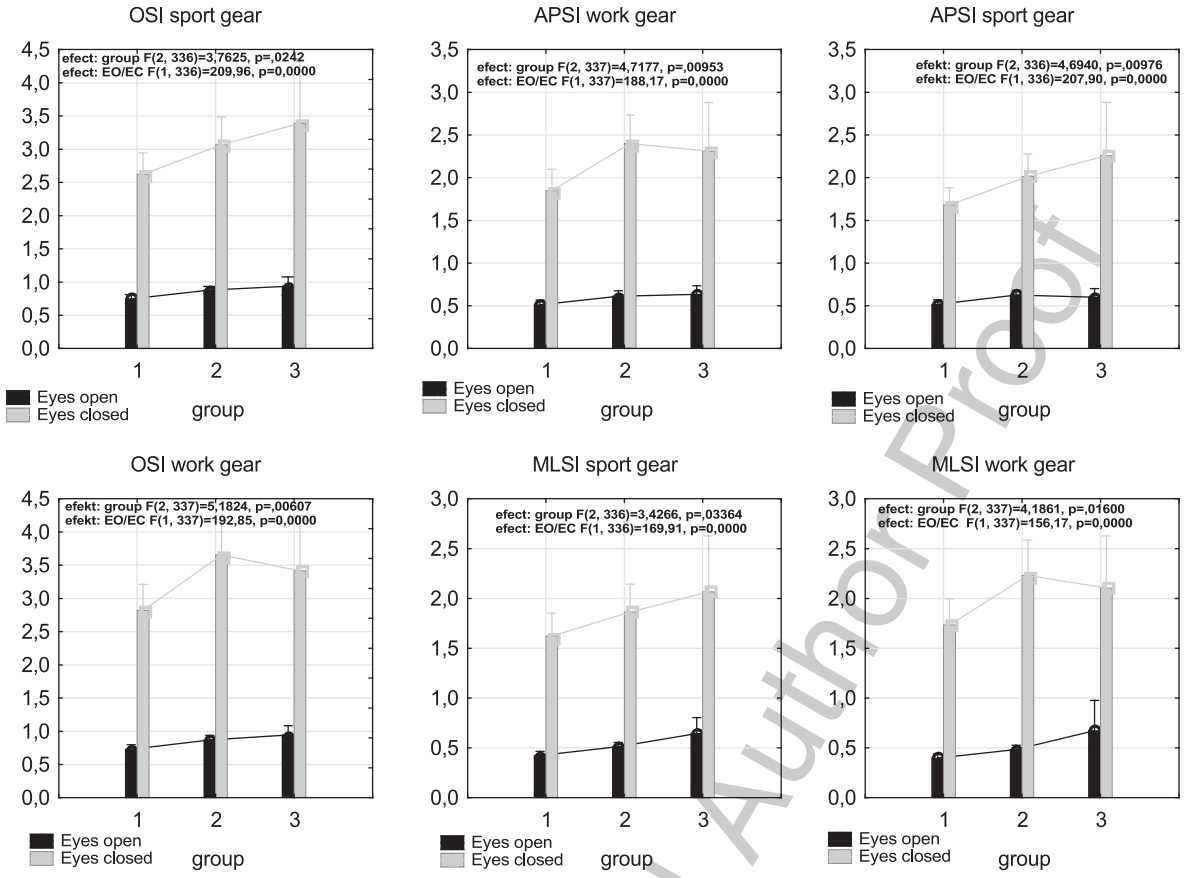

Fig. 1. Results for stability indexes for eyes open and eyes closed in age groups.

mask [29] and self-contained breathing apparatus (SCBA) [30]. Hur et al. [30] suggest re-design of the air cylinder apparatuses. Their weight, size (height and base diameter) should be reduced while the centre of mass should be located closer to the firefighter's body, that's why next research should include tests with the extra equipment. Sobeih, Davis [31] used a static platform to evaluate the effect of shift duration on postural stability in a bunker gear. The study showed that stability indices of firefighters wearing bunker gear with and without SCBAs were improved compared to the sportswear. Furthermore, a negative effect on postural control was documented for the shift duration.

Examinations with simulated fire conditions would provide more insights into this problem. Factors such as stress, fatigue, high temperature and variable texture of the ground on which the firefighter stands, should be analysed [32–34].

This study indicated that under conditions of visual input and constant instability of the platform, the firefighters maintained good postural stability. However, in the tests with eyes closed, balance was substantially deteriorated. The biggest differences in participants were observed between eyes open and eyes closed. This finding demonstrates that a decline in postural stability can be diagnosed by the tests with eyes closed and this can be the indication for performing such tests and implementation of training routines with exercises in the absence of vision [35]. Vision performs a compensatory role for other sensory inputs [36]. Therefore, with a good visibility, the decline in proprioception or function of the vestibular system can fail to be detected. Slips, trips, and falls are the most significant causes of moderate or severe injuries of firefighters (28%) [37]. Therefore, it is essential to maintain good postural balance under conditions of eyes closed. During a slip or trip, the firefighter usually does not have a chance to prepare for the obstacle he or she cannot see. Therefore, improved postural stability without visual input reduces fall risk.

Another factor that impacts on the results of balance is firefighter's age [5]. We divided the participants into three age groups. It was found that under conditions of eyes open, the results were deteriorated with age but the differences were not statistically significant, whereas the absence of visual input led to a statistically significant decline in all results, both in sportswear and bunker gear. This is consistent with the study performed by Punakallio [38], who compared two age groups: 33 to 38 years and 43 to 56 years of age. The latter group obtained worse results on a static balance platform. We observed the greatest reduction of results between ages 25 and 43. Older firefighters may be more susceptible to thermal injury while on duty than their younger counterparts [39]. It should be emphasized that no reduction in stability was observed between the second and third groups, which might suggest a high level of fitness and experience of older firefighters. This is consistent with the findings published by Bakri, Son [40], who demonstrated the effect of experience and training on stability indices. Moreover, the fatigue factor during firefighting emergencies is also essential as fatigue leads to higher number of mistakes in postural control [41]. An important factor in fall prevention is training of the ability of the firefighter to immediately regain balance [42]. Adequate education and postural stability training are critical. It is obvious that physical activity is needed for proper function of human body at any age [43]. There is substantial evidence that exercises have an effect on the improvement in balance [19, 44, 45] and thus specific training to improve postural stability should be designed into firefighting training programs.

Our study demonstrated the need for implementation of special firefighter training aimed at the improvement of stability indices in rescuers, with the emphasis on routines performed with eyes closed when the firefighter is wearing bunker gear. Firefighters perform strenuous muscular work; they must climb stairs and ladders, carry and use heavy tools, often above their head or in awkward positions, and they may be called to perform difficult rescue operations [46]. The safety of the public and the health and safety of firefighters would be enhanced if firefighters followed well-designed fitness programs to improve overall health and fitness [46].

Comparison of the results depending on the participants' age would demonstrate the legitimacy of this training and maintaining a high level of balance in firefighters [47].

Insufficient level of postural balance was found in 39 people, which indicates the need for training. The results of the postural stability tests performed in sportswear and bunker gear should be analysed during designing of protocols for special firefighting training and in prevention of falls during emergencies [48]. The methodology of special firefighting training should take into consideration training with reduced visual input mimicking potential working conditions during a firefighting emergency. Drills should also be conducted in bunker gear for the same reason.

As a result, for the purpose of preventing musculoskeletal injuries and improving performance within populations that are exposed to highly variable task demands (e.g., athletes, firefighters, and military service personnel), it could be questioned whether conventional approaches to exercise are sufficient [48]. Firefighter training is essential in ensuring the safety of families all over the world. As a society we should care about their training, because when firefighters training will be better, they will be more prepared for dangerous situation and we as a regular people will be safer.

3.3. Limitations

The aim of this research was to identify key factors that impact postural stability patterns of firefighters. This will allow minimalizing fall risk among this population. However, our study had two limitations. First limitation was the fact that it did not include tests in self-contained breathing apparatus (SCBA) and full-face mask. Based on our study, we believe that it may be the previously mentioned equipment that, in line with other research, have substantial impact on firefighters' stability. Next limitation in our research were age groups. Division of participants into particular age groups was determined by regulation about physical fitness of professional firefighters. To identify all the factors, it is recommended to continue research in self-contained breathing apparatus (SCBA) and full-face mask. Study in different age groups should also be performed.

4. Conclusions

Our study found that bunker gear worn without a SCBA and a mask does not have a significant effect on balance results. We also identified two important factors that impact postural stability patterns

of firefighters – age factor and presence of visual input. Older firefighters are at higher fall risk than younger ones. Moreover, absence of visual input leads to significant decrease in balance and higher fall risk. Providing the best possible visibility is a key to firefighters' safety. However, this is not always possible, because of unpredictable environment, extreme temperatures, toxic fumes and stress. Therefore, improvement of postural stability with eyes closed is crucial to increasing firefighters' safety during rescue operation but also people being rescued. Prevention of falls and injuries should be supported by special balance training to reflect working conditions of firefighters.

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Conflict of interest

None to report.

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