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Human movement analysis in evaluation of the risk of falls in younger and older workers while wearing protective footwear

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ABSTRACT

The objective of the work was to determine whether human movement analysis would reveal differences between younger and older workers using two types of protective footwear. The study group was composed of 40 males (20 younger and 20 older subjects). Two types of protective footwear differing in terms of construction were selected: sandal-like footwear with a low shoe collar (type A) and ankle boots with a high collar and ankle support (type B). The subjects performed simple activities, such as walking on a treadmill and climbing stairs. Measurements involved angles at the right and left knee, hip, and talocrural joints. It was found that gait analysis is not sufficiently sensitive to determine which protective footwear construction leads to a greater risk of falling in younger and older workers. The tests did provide information concerning differences in gait biomechanics between younger and older subjects wearing protective footwear.

1. Introduction

Falls are a major cause of accidents in the workplace. Most slip-related falls on the same level occur in the food and food service industries, the construction industry, healthcare, and transport services [1]. It has been noted that certain design features used in casual footwear (ankle support, heel height, sole type) may significantly affect the risk of slips and falls [2–4].

The risk of falling is also determined by individual characteristics, such as age-related motor performance, which is particularly important in older workers, aged 65 years and more. It should be noted that involution processes result in limiting the range of motion, with the strength of the lower limbs reduced by up to 40%, a lower muscle tone, and balance impairments, increasing the risk of falls [3,5,6].

In the context of falls, a significant risk for workers is presented by slippery and uneven surfaces. Slip prevention involves the use of protective footwear with good adhesion to both dry surfaces as well as surfaces contaminated with water, oils, greases, etc. Of great importance is the sole tread, which should increase friction and facilitate the removal of liquids from under the sole. The applicable standards used for evaluation of the conformity of protective footwear with the basic requirements of Directive 89/686/EEC assess slip resistance, which is critical for all types of occupational footwear. This parameter is assessed in instrumental tests of new footwear by measuring the dynamometric coefficient of friction between the sole and a model walking surface (ceramic and metal floor) covered with a test lubricant [7]. This parameter is measured for different constructions of protective footwear: shoes (model A), ankle boots (model B), calf-length boots (model C), knee-length boots (model D), and thigh boots (model E) [8].

Having older workers in mind, it is essential to determine which types of protective footwear construction carry a greater risk of falling. To that end, the biomechanical risk factors should be evaluated through human movement analysis. So far, research into the risk of falls has been focused on casual footwear. There are no data concerning the effect of the upper construction of slip-resistant protective footwear on the risk of falling. However, this issue is important from the viewpoint of the occupational health of older workers, who require personal protection equipment which would be adequate both in terms of protective and ergonomic parameters as confirmed by tests taking into account age and motor abilities.

The objective of the present work was to determine whether gait analysis would be a useful method in evaluating the risk of falling and reveal differences between protective footwear of different constructions worn by older and younger workers.

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2. Methods

2.1. Protective footwear

The study examined two types of protective footwear differing in terms of construction: footwear with a low shoe collar (type A) and ankle boots (type B). The characteristics of the footwear are given in Table 1, while selected tests concerning its protective parameters are presented in Table 2. Tested footwear is a Category II of Directive 89/686/EEC.

2.2. Subjects

The study involved 40 males, including 20 younger (Y) and 20 older (O) subjects, who were professionally active and used different types of protective footwear in their various occupations. The younger group contained firefighters, drivers, and farmers, while the older group was composed of farmers and security personnel. The study group is characterized in Table 3.

During the tests every subject wore a two-piece cotton/polyester (50%/50%) tracksuit: shorts and t-shirt. The footwear, socks, and clothing were acclimatized in the laboratory at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 5)%.

Tests were conducted in a laboratory under controlled climatic conditions: at a temperature of (23 ± 2) °C, a relative humidity of (50 ± 5)%, and an air movement not more than 0.10 m/s [8]. The tests were voluntary and conducted pursuant to the basic procedures applicable in scientific metrology. Every participant was informed about the experimental protocol and test variants, which are shown in Table 4.

2.3. Gait analysis

Gait was recorded and analyzed using a FAB 13 human movement analysis system (Noraxon) with FAB Recorder 1.08 software, consisting of:

- Thirteen wireless 3D motion capture sensors;
- A signal receiver connected to the computer through an USB port;
- Software for system calibration prior to the tests, recording the position of individual body segments, graphical representation of the body during measurements, and exporting measurement results.

Signals from the sensors were radio-transmitted to the receiver connected to the computer. Every measurement was preceded by 30 s sensor calibration according to the procedure specified in the FAB Recorder manual. Subsequently, the subjects performed two functional tests:

- Treadmill test: walking on a treadmill for 1 min at 7 km/h;
- Stair-climbing test: 3 cycles of ascending and descending 13 stairs (a total of 78 stairs).

The tests were selected based on the literature data. While approx. 60% of falls of elderly persons occur while walking [9]. One multi-center study showed that most falls result from slips (36%) on stairs, steps, and curbs (23%) [3]. The exercises performed in the functional tests are presented in Figs. 1 and 2. The parameters measured during the treadmill and stair-climbing tests were angles at the knee, hip, and talocrural joints of the left and right lower limbs.

2.4. Statistical analysis

The overarching research objective of the study was evaluation of differences in the tested parameters in two areas:

- Evaluation of differences in average parameter values between the older and younger groups;
- Evaluation of differences in average parameter values between the two footwear types.

In order to test the research hypotheses, statistical analysis took into account the following:

- the type of relationship between the groups – independent or dependent;
- number of compared groups – 2 or more than 2;
- type of variables – quantitative, ordinal, or nominal;
- normal data distribution (2 groups) or homogeneity of variance (more than 2 groups) within the compared groups.

In the first part of the study, differences between the results obtained by the older and younger groups were evaluated with Student's *t*-test or the Cochran-Cox test, following testing for normality of distribution. Intergroup comparisons were conducted using analysis of variance (ANOVA).

In the second part of the study, evaluation of differences between the gait analysis results for the studied types of footwear was based on the *F*-test for variance with a post hoc Bonferroni correction.

The significance level for all statistical tests was adopted at $p = 0.05$. The null hypothesis was that no statistically significant differences existed between the studied groups. Consequently, if the probability value, *p*, obtained in a given statistical test was higher than the adopted significance level ($p > 0.05$), the null hypothesis was not rejected.

Analysis was conducted using SPSS Statistics 21.0 software.

Table 1
Characteristics of the studied protective footwear (EN ISO 20345:2011).

Footwear type	Photograph of footwear
Type A – Sandal-like protective footwear	
Type B – Protective ankle boots	

3. Results

Human movement analysis enabled measurement of angles at the hip, knee, and talocrural joints in the course of performing