Description and profile of the journal

Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) is the official, reviewed, quarterly academic publication of the International Association of Sport Kinesiology (IASK), issued by the University of Physical Education in Krakow since 1989, and from 2010, in cooperation with the University School of Physical Education in Wroclaw. The journal has received academic patronage from the Rehabilitation, Physical Education and Social Integration Committee of the Polish Academy of Sciences and can be found in the IC Journal Master List international indexing database. Since 2014, the journal is published in the original electronic version in English. On subscribers’ request, the journal may be issued in English and Polish in book format.

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Aim

In Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) the results of innovative experiments and observations on human locomotive activities conducted under natural and laboratory conditions by researchers of human motor skills (anthropomotorics) or related fields and disciplines, such as: physiology, psychology, physical anthropology, biomechanics, medicine, computer sciences, economics, genetics, pedagogy, sports education are presented. This allows to acquaint oneself with the essence of human physical activities, their structure, skills, motor functions and aptitudes, learning of these motor functions, their monitoring and control, and the health and sports effects of the broadly understood human notion of physical activity.

In accordance with the aim of the journal, the subject of the article should fall under one of the four thematic categories:

I. Theoretical and applied aspects of kinesiology (Fundamental and Applied Kinesiology).
II. Scientific basis of motor function training in sports and recreation (Sport Sciences).
III. Teaching, controlling and monitoring motor functions. Scientific basis, formation and evaluation of activity and physical fitness (Exercise Sciences).
IV. Reviews, debates and discussions, historical elaborations, conference announcements, reports from conferences and congresses of the IASK and brief summaries of papers printed in foreign journals, book reviews on the theory of human motor skills and also, assessment of the current state and prospects for the development in anthropomotoric research achievements (Varia).

Papers of high scientific value previously qualified for publication in another foreign journal may also be submitted, provided that the author obtains written consent to reprint the article from the foreign journal in which the text has been or will be published.

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- Once registered on the IC Publishers Panel platform, authors should contact the editorial office via the IC Publishers Panel e-mail or the editorial office directly via e-mail: antropomotoryka@awf.krakow.pl
- The author responsible for correspondence with the publisher concerning the article receives notification confirming submission of the article, and information about stages of its publication.
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Texts submitted for publication should be written in English or Polish in accordance with the following editorial requirements:

- The volume of empirical work including the summary, figures and tables should not exceed 22 pages, and the reviews – 30 pages standard A4 size (up to 1,800 characters including spaces per page);
Texts should be prepared using only Microsoft Office Word text editor, pages should be numbered, font: Times New Roman; size: 12 points; spacing: 1.5; justified text; title written in bold typeface; centred.

Tables and figures labelled using Arabic numerals and headers, explanations and descriptions of illustrations below the figures and the results above the tables should be placed on separate pages in the **English and Polish versions**. Headers, explanations and descriptions below the figures and above the tables should be in English and Polish.

Example:

Tabela 1., Ryc. 1., Objaśnienia, Chłopcy
Table 1., Fig. 1., Commentary, Boys

Figures and tables should be placed on separate pages (See: Illustrative material);

**Title page** (English and Polish versions on separate pages – if article is meant for publication in both English and Polish) containing the full title of the paper and its short title (up to 40 characters including spaces) to be placed in the running head, names of author(s), affiliation of the author(s) presented according to the following scheme: faculty, university, country, contribution of the co-authors in the creation of the article using symbols in the case of collective works (pattern of symbols according to the instructions in IC Publishers Panel); mailing address of the lead author (author’s full name, address, e-mail address and phone number).

**Abstract and key words** (English and Polish versions on separate pages – if article is meant for publication in both English and Polish), taking the following structure into account:

- **Full title of the work, summary** about 250 words with division into parts: (in English) **Purpose, Basic procedures, Main findings, Conclusions** (in Polish: **Cel pracy, Materiały i metody, Wyniki, Wnioski**), **keywords** containing from 3 to 15 words (preferably using the MeSH dictionary);

**The main body of the text** (in English and Polish)

The main body of the text should include the following parts:

- **Introduction**. Introduction acquaints the reader with the subject of the article and places it against the background of existing research (literature review). At the end of the introduction, the aim, research problems and hypotheses should be clearly stated.

- **Material and methods**. An accurate description of the research subject (material) should be presented in the methodological part. The number of subjects, their age, sex and other characteristics of the participants should be indicated. Additionally, information regarding the conditions of testing, time and methods, techniques and research instruments, with particular emphasis on the description of the used apparatus should be given. The name and address of its producer should be given. If an original method or technique of research was used, it should be described precisely by presenting its validity and reliability (reproducibility). In the case of modifying already recognized methods, the applied changes must be described and the need for these changes must be justified. Statistical methods should be explained so that it can be easily determined whether they are properly suited for the purpose of research. The author of the review or meta-analysis should provide methods of searching for materials, methods of selection, etc.

- **Results**. Presentation of the results should be logical and cohesive, and closely linked to the data in the tables and figures. Referencing results presented in the tables or figures, the abbreviated name of the table and figures (Table 1, Fig. 2) should be placed in parentheses and on the margins of the work, suggesting their location in the comments. In the main body of the paper, the same results in tables and figures cannot be repeated.

- **Discussion**. The author should relate the results to data from literature (other than described in the introduction), highlighting the innovative and significant aspects of his/her work. The adopted hypotheses should be verified or falsified.

- **Conclusions**. Presenting cognitive and applicative findings, the posed hypotheses should be considered and vague statements not supported by the results of the research should be avoided.

- **Acknowledgements**. A list of persons or institution(s) contributing to the preparation of the article, financially or technically supporting the research process or article publication may be given. It is particularly desirable to provide the study grant number.

- **References**. The bibliographic list contains only items which are referenced in the body of the text. Bibliographic descriptions, enumerated using Arabic numerals and listed in the order of citation (not in alphabetical order) should be printed on a separate page. Each referenced item should start with a new line. The **sequenced number of the bibliographical item, given in square brackets, must correspond to the order of reference** to the publication in the body of the text.

**Bibliographic description of the article should include:**

- the name of the author(s), initial(s), surname(s), title of the article, name of the journal in functioning abbreviated form, year of publication, issue, volume number, pages, DOI number (if the publication has one). Bibliographic description should end with a full stop.

The Vancouver Referencing Style, also known as the author-number system of citation, recommended for medical sciences should be used in the publication (https://www.library.uq.edu.au/training/citation/vancouver.pdf). Enumeration of the referenced texts and principles of citation are defined by the so called Vancouver Convention drawn up by the **ICMJE (International Committee of Medical Journal Editors)**. According to it, referencing material from the source in the body of the text should end in the bibliographic item number in square brackets, e.g. [1]. In the case that reference is made to the authors, the reference is placed immediately after the author’s surname (without first name initial) (e.g.: “According to Aronson et al. [23] this study is ...”).

Repetition of the reference to the same publication is done by its earlier established number. References of attachments are organized according to the order of their citation in the body of the text. Citing two or more publications should be included in square brackets in chronological order of their publication.

Explanatory notes or supplementary text should be numbered using the **Oxford Referencing System**, maintaining consistency throughout the article.
Examples

Monograph by no more than six authors:

Monograph by more than six authors. After the sixth author, the following abbreviation is placed: et al.

Subsequent editions of the monograph (Edition number is placed after the title)

Monograph publisher (collaborative work)

Chapter in the monograph (collaborative work)

Conference reports (papers)

Monographs published in electronic version

Articles in journals. Standard, list only six authors, above six—abbreviated: et al.

Articles published in journal supplements

Articles in journals published in electronic version without DOI (digital object identifier). Enter the URL (Uniform Resource Locator) – journal website

Articles in journals published in electronic version, with digital DOI

Articles in journals published in electronic version, found in the PubMed database.

Important information for authors of articles submitted for publication
In view of the fact that since 2014 onwards, the quarterly journal will be published in the original electronic version in English, please translate into English: titles of articles in the bibliographic listing published in a language other than English, providing the language of the original in square brackets after the English title. The title of the journal must remain in full version or in functioning abbreviated form. Example:


The National Library of Medicine recommends placing the English translation of the title in square brackets, and information regarding the language of the article after the page

Example:


Illustrative material

- **Technical requirements**
  - **Figures** – should follow a consistent background colour scheme; do not use grid lines or shading.
  - **Tables** – standardized format, reducing grid lines to a minimum.

Example:

<p>| Table 1. Differences (d) in body height and mass as well as BMI between student group A and B |
|------------------------------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Group Variable</th>
<th>A: Me (SD)</th>
<th>B: Me (SD)</th>
<th>d</th>
<th>Significance level p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>21.5 (3.2)</td>
<td>22.0 (1.5)</td>
<td>–0.5</td>
<td></td>
</tr>
<tr>
<td>Body height [cm]</td>
<td>176.2 (3.3)</td>
<td>178.0 (4.1)</td>
<td>–1.8</td>
<td>0.567 *</td>
</tr>
<tr>
<td>Body mass [kg]</td>
<td>68.3 (2.7)</td>
<td>79.4 (3.5)</td>
<td>–11.1</td>
<td>0.005 **</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>22.3 (2.2)</td>
<td>25.7 (2.8)</td>
<td>–3.4</td>
<td>0.006 **</td>
</tr>
</tbody>
</table>

NS – statistically non-significant difference

* – p<0.05; ** p<0.05; ***p<0.001

**Scanning.** The resolution of scanned illustrations must be at least 300 dpi. Black and white illustrations (lines of the art.) should be in TIFF format, or colour and images (grey) in TIFF or JPEG format (low degree of compression, up to 10%). All files can be compressed using RAR or ZIP; **Symbols,** for example: arrows, asterisks or the abbreviations used in tables or figures should be clearly explained in the legend. **Equations** must be written legibly, especially indices and exponents in powers.

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**Appropriate Procedures of Reviewing in the Sciences:**

**Veracity in Scientific Research and Respect for Intellectual Property:**
http://bbn.uksw.edu.pl/node/76

**Ethical Principles of a Scientific Researcher:**

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- The publisher decides whether the article will be released for publication based on the reviewers’ opinions and the responses of the authors or lead author to the reviewers’ comments.
- After translated, proofread and edited, the article is sent to the author(s) for approval. The publisher sets a one-week deadline for submission of further modifications by the author.
- Before publication, the author responsible for correspondence with the publishing office will receive the article by e-mail (in PDF format), edited in accordance with the journal’s style template, to obtain consent for its publication. At this stage of publishing, only minor, final modifications may be made. Delay in re-submission/consent may cause the article to be moved to the next issue.

Concluding remarks

- **Publication of articles in Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) is free of charge.**
- The author responsible for correspondence concerning the article receives a free PDF file with the issue of the quarterly journal, in which his/her paper is published.
- **Abstracts and full texts in English and Polish are posted on the following websites:** http://www.antropomotoryka.pl/ and http://970.indexcopernicus.com/
- **Subscription** to issues of the journal published in book format can be ordered for a fee at: joanna.stepien@awf.krakow.pl.
- **Distribution and sales** of current and archival issues of “Antropomotoryka. Journal of Kinesiology and Exercise Science” can be found at:
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EDITOR-IN-CHIEF’S FOREWORD

FOR THE LAST TIME IN 2015, WE ENCOURAGE OUR READERS TO HAVE A LOOK AT THE 72ND ISSUE OF KRAKOW-WROCLAW ANTROPOMOTORYKA – JOURNAL OF KINESIOLOGY AND EXERCISE SCIENCES.

The year 2015 is nearing to an end. Antropomotoryka. Journal of Kinesiology and Exercise Sciences is already 27 years old. However, there is no time, on the verge of the new year, to ponder on the past; neither are we going to calculate last year’s gains and losses. For us, the staff, the future and faith in progress is what counts: may the increase of over 100% in the score assigned to our journal by the Polish Ministry of Science and Higher Education testify to that. Antropomotoryka is published under the auspices of the Index Copernicus online database – we express our gratitude for our cooperation so far and want it to continue. Index Copernicus is a very demanding patron. Our paths do not always cross, but we believe that we will not lose our way as long as we walk together. We hope that each future issue of our magazine will be even better than the previous one, and lead us to an even higher evaluation.

We also thank our contributors – the co-authors of the project of popularising the up-to-date state of knowledge of human movement. It is thanks to them, thanks to every article of theirs, thanks to each review, that together we become better. We are also very pleased with the ever-increasing number of articles sent in to the editors which we can publish after they have been thoroughly reviewed. This means that we are able to give our readers the new, 72nd issue of Antropomotoryka. It contains 9 articles. All of them may be of interest for those seeking new research related to men in action in the broader sense. It also includes very inspiring reflections of an Antropomotoryka contributor whose fame has already crossed the Polish border.

The narrator of the somewhat meta-analytic “A scientific evening with N.A. Bernstein, G.A. Miller and A.G. Feldman” invites to the meeting table the “giants” of motor control research mentioned in the title. The inspiration for the creation of the fictional scene was a conversation over dinner of two extraordinary composers, presented in a play by the German writer P. Barza, entitled “The possible encounter between Mr. Bach and Mr. Haendel”. Their songs have stood the test of time; in the age in which they lived, they enjoyed high status and social prestige. G.F. Haendel was a recognised composer, whereas J.S. Bach had only a modest position of the cantor at St. Thomas’ Church in Leipzig.

According to the motto of the article “The road to success is always under construction” by Lily Tomlin, the aim of carrying out a meta-analysis and arranging the fictional scientific meeting in the recommended study was an attempt to merge the views of other “giants”. This time, they are the researchers of motor control and human psychology: “G.A. Miller (the “magical number 7 ± 2”), N.A. Bernstein (the “Bernstein Problem: reduction of freedom degrees”), and A.G. Feldman (“Equilibrium Point Hypothesis”).

The synthesis of the collected material was enriched with a very briefly described research field exploring the structure of human motor skills, based on the results of quantitative traits studies. In this case, European (including Polish) achievements in the field were passed over. The discussion is limited mainly to quoting the critical assessment of the statistical method of examining the structure of human motor skills, represented in the 1950s by E. A. Fleishman, among others. The position was also supported by the opinion issued by R.A. Schmidt and T.D. Lee, contemporary American control and motor control researchers, that “Fleishman’s work leaves a legacy for future efforts on solving problems of prediction.” After reading the paper one can get the impression that the results of the analysis of the collected material confirm the hypothesis by the mathematician R. Thom in the introduction: “great achievements we owe no more to discovery of new facts, but they appear rather as new ways of thinking or interpretations of already known facts”.

The next meta-analytic work, namely “Oxidative stress and training” draws the readers’ attention to the very important achievements of scientific research. The aim of the study was to determine the effect of different sports on the prooxidative-antioxidant blood status among. The subject of the study was the results of research published from 2011 to June 2015 in journals listed in Medline, PubMed and Google Scholar databases. The initial selection included materials published in 570 scientific articles, containing the
following key words: “oxidative stress and sport”, “oxidative stress and athletes”, “oxidative stress and endurance”, “free radicals and sport”, “free radicals and athletes” “free radicals and endurance.”

The next two empirical studies take up the issue of body balance. The article “Force asymmetry indicator in the assessment of maintaining human body balance in an upright position force asymmetry indicator (FAI)” contains verification of the accuracy of the measurements of the above-mentioned coordination capacity. The cognitive aim of the study was described as follows: To examine the possibility of using the direct measurements of the ground reaction force components (in response to right and left foot pressure) as a function of time, along with the force asymmetry indicator (FAI) created from the measurement values, to assess the laterality and symmetry of functioning of feet while performing weight transmission and balancing functions when maintaining erect posture. Measurements were performed on a group of 82 people (31 women and 51 men). Advanced statistical methods were used to work on the material. The results allowed to identify the main determinants of the natural balance of the body (in both men and women) and to develop the force asymmetry indicator of the lower limbs in standing position.

In terms of cognition and application, the results of the research presented in the article “The influence of an additional load on rambling-trembling cop signal decomposition” are very interesting. The article tackles the issue of how big an impact an additional weight of 7 and 10 kg has on the stability of posture of 30 students.

In most cases, the results suggest the occurrence of adverse effects of the rapid changes in the size and geometry of the body to its balance. Undoubtedly, these findings provide further evidence on the negative impact of overweight and obesity on an important motor component of physical health.

“Flexibility evaluation in women aged 50-80 years in Poland, in the kujawsko-pomorskie voivodeship” presents variability in the course of ontogenesis of another important component of physical health, that is joint mobility. It presents the results of a population study of a group of 3,413 elderly women. The test results unmistakably indicate that flexibility diminishes with age. Secondly, both of the evaluating tests must be performed in order to achieve proper global shoulder girdle flexibility evaluation. From the findings of the study, it can be shown that flexibility regression occurs to a greater extent in the upper limbs than in lumbar-pelvic complex.

Two subsequent articles add to the knowledge of the role of the method of performing a motor task. On the basis of a very thorough analysis of the biomechanical structure of the kinematic and dynamic mechanical movement in bench press (weightlifting), the authors of “The type of bench press based on the critical features of the type of bench press” divided the athletes, using statistical cluster analysis, into two groups: 1, was the group which lifted the barbell at a slower tempo and did so at small values of the average power. 2, was the group which quickly lifted the barbell and did so at high values of the average power.

In the work entitled “Functional movement screen as a tool for functional evaluation and prediction of the risk of injury among floorball athletes rating floorballers by using the FMS” the authors, with the use of tools called Force Asymmetry Indicator (FAI) and the Functional Movement Screen Test (FMS) made a successful attempt at an assessment of the technical patterns of 23 male players aged 16-18 years who played floorball professionally. On the basis of the collected material, the authors made an attempt to verify the disorders in fundamental movement patterns occurring in young floorball players and the relationship between the observed disorders and the occurrence of injuries. The analysis of the collected data gave a reason to conclude that the use of the Functional Movement Screen Test in young floorball athletes, can detect asymmetry and dysfunction associated with the specifics of practicing this sport. The obtained FMS test result correlates with the history of injuries and contusions. The FMS test is an inexpensive and quick tool for functional assessment and seems to be a useful test for early detection of abnormalities in the patterns and asymmetry of floorball players. In turn, it can prevent and reduce the risk of injury, which is particularly important in young players – juniors.

The work entitled “The personality of highly trained athletes in view of the big five model” presents the results of the study on personality of players practicing short- and long-distance running, triathlon, futsal and taekwondo. The collected material allowed to verify the hypothesis that high-class athletes differ from the general population in terms of personality traits. As a result, it was found that there is a need to know the individual mental characteristics of athletes to optimise training.

As it can be seen from the short presentation of the works published in the mostrecent issue of Antropomotoryka, most of them encourage their readers to enter into discussion with the content. One can only hope that the discussions will not be artificially provoked.

We expect the discussions, and we will publish them in the section “Polemics and discussions”. However, referring to the atmosphere of discussion at dinner it is difficult not to recall one of them with the release of the last number in December. Families gather around the table to have supper, but only after a sigh and mutual wishes. It is also right for the editor-in-chief to wish the closest editorial family of Antropomotoryka, as well as those scattered around the country and abroad a very happy new year. Let it be just as successful as the almost-concluded 2015.

Edward Mleczko
Editor-in-Chief
Abstract
Theoretical analyses make the essence of motor control to a much greater extent than in any other scientific physical culture discipline. In this field, there are many achievements of outstanding scientists. However, these achievements are often regarded as unshakeable monuments. Moreover, they are often intellectually dispersed. Hence, one of the most important current tasks of motor control – all over the world – is to reinterpret these achievements and join them together, i.e., to make them a coherent, efficient system. The system produces qualitatively new, unpredictable system effects, which in the case of motor control creates the only way towards great progress. This paper makes an attempt at joining the concepts by G.A. Miller (the “magical number 7±2”), N.A. Bernstein (the “Bernstein Problem”: reduction of freedom degrees), and A.G. Feldman (Equilibrium Point Hypothesis).

Introduction
In his play “The possible encounter between Mr. Bach and Mr. Händel”, the novelist P. Barz presented a hypothetical dinner, held by the famous composer G.F. Händel for the humble cantor from St. Thomas church in Leipzig, J.S. Bach. Such a literary convention enabled the confrontation of genius of both these Giants without relating it to real, historical events. This gives much freedom in theoretical analyses because it becomes possible to compare pure intellect and reject the historical context which usually is not significant. Hence, also using such a convention in scientific analyses seems to be promising.

At first it seems worth noting that the only manifestation of any mental process in a living being – including a human – is movement, even if only that of the lips and tongue. In other words, there is no behavior other than the motor one.

Research into human behavior intensively developed during World War 2 for military purposes. However, in the 1950s they started to die out, all over the world. Some of them, such as statistical research on motor abilities initiated by E.A. Fleishman, turned out to be a dead end [1]. R.A. Schmidt and T.D. Lee have stated that “Fleishman’s work leaves a legacy for future efforts on solving problems of prediction” [2]. This would be great, indeed, because according to the outstanding mathematician R. Thom, “great achievements we owe no more to discovery of new facts, but they appear rather as new ways of thinking or interpretations of already known facts.”
Unfortunately, it is not sure whether the next generations of scientists will be interested in analyzing and developing the knowledge already put out to pasture. Much more seductive is to use new, fascinating measurement devices for researching into “influence something onto something” or “measuring something in somebody” – which is light, easy and safe – rather than to take on arduous and risky work to create a theory. However, just the latter constitutes the very “salt” of science. Unfortunately, the experimental works often contribute to merely extending the useless “cemeteries of facts” – this term has been coined by the mathematician R. Thom – and not enriching science.

In the West, the process of gradual dying out of motor control led to a symbolic “academic funeral” of this discipline in the mid-sixties, arranged by I. and E. Bilodeau [2]. In pre-revolution Russia and in the Soviet Union seminal were the works by I.M. Sechenov [4], which strongly influenced the famous Nobel laureate I.P. Pavlov. His reflex theory was indeed very innovative at that time. However, along with the passage of time, Pavlov’s achievements – paradoxically – inhibited the progress of science more and more [5]. They especially suppressed the attainments of N.A. Bernstein [6], which were interpreted not as the development of the “only right” – the then – theory by Pavlov, but as an attempt at debunking it. Hence, the infamous “Pavlovian session” [7] officially established the reflexive model by I.P. Pavlov as the “unshakeable” one. As a result, the achievements of N.A. Bernstein and P.K. Anokhin (the latter was no doubt the most outstanding Pavlov’s disciple), systemic in their nature, have been condemned, and their authors – severely punished, in typical Soviet style.

In psychology, behaviorism dominated until the 1950s. Its founder, J.B. Watson [8] was strongly influenced by the ideas of I.P. Pavlov [9]. The central element of this scientific paradigm was the “black box” [10, 11]. According to the main behavioristic idea, scientific was only what might be observed, counted or measured. The place for other items was just a “black box”. Paradoxically enough, one could hardly imagine something more contradictory to the general idea of behaviorism than the elusive and slightly (or even more than “slightly”) charlatanic “black box”. All the items which did not meet the behavioristic criteria – obvious, countable or measurable – were directed towards the “black box” and there, miraculously, gained the trait of some kind scientific(al)ity, or at least “tolerability in science”.

By the way: According to the “Urban Dictionary” the word “scientific” – sounding nearly identical as “scientific” – means “a way to make yourself sound intelligent when you have no idea what you are talking about” [12]. I cannot help feeling that the “black box” is essentially scientific rather than scientific.

In Russia, the scientists who went another, non-behavioristic way – though they did not declare it openly – were N.A. Bernstein [6] and P.K. Anokhin [13]. In America, the breakthrough was brought about by the seminal paper of G.A. Miller [14], which N. Cowan [15] and B.L. Bachelder [16, 17] termed “one of the most influential papers in psychology”.

In 1956, cognitive science sprouted along with works by G.A. Miller, N. Chomsky and J.S. Bruner. The latter wrote:

I think it should be clear to you by now that we were not out to “reform” behaviorism, but to replace it. As my colleague George Miller put it some years later, “We nailed our new credo to the door, and waited to see what would happen. All went very well, so well, in fact, that in the end we may have been the victims of our success” [18].

The general space in which human behavior is being anchored, consists of three circles:
2. The mechanism for its extension – science.
3. The region stretching beyond the possible scientific methodologies, where only abstract reasoning may build an image of reality (or, more exactly, meta-reality) – philosophy.

One might create an image of relations between them, as presented in Figure 1 [19].

Physics, biology, and psychology

The most primeval roots of behaviorism can be traced in the statement by I. Newton “hypotheses non lingo” [20]. It may be interpreted as the credo of empiricists. It turned out to be very productive – at least in the 17th century – in physics where stimulus is directly coupled to a reaction [21].

Non-living subjects are completely indifferent to the future. They do not dispose of memory, so their previous “experiences” do not influence their current behavior. As a result, the behavior of physical subjects may be easily predicted and described mathematically, even if – as in quantum physics – in statistical or probabilistic terms.

However, the explanatory power of “hard facts”, and not elusive and intellectually fuzzy hypotheses, exhausted its potentialities on the border between the non-living and living world. According to T. Gánti, each living system “must have a subsystem carrying information which is useful for the whole system” [22]. Thus, in living beings – unlike non-living subjects – an attitude appeared towards the future, based on previous history of the system, of the species’ or an individual’s nature. It may be identified with embryonic anticipation. So, the cause-effect chain in living organisms became longer
and consisted of three links: stimulus – information – response; no longer sheer reaction!

At first, the product of such embryonic anticipation was purposefulness of passive nature. It is only inherited and cannot be actively modified by a living organism. If in a given specific situation, the inherited biological mechanism or way of behavior turned out to be wrong, the organism had to die. This was the basis for natural selection, which at the very roots underlies the process of evolution.

Along with the development of living creatures, passive purposefulness gradually transformed into active intentionality. A living being became able to build the image of future events in its mind and adjust its current behavior to this image. And thus, along with the invention of language, immune to the passage of time, the psyche is born. M. Heller argued that: “the notion, while already born, multiply and mutate quicker than biological species” [23; transl. WP]. As K. Popper elegantly put it, “this design enhancement permits our hypotheses to die in our stead” [24]. At that point of development, the ability to predict became a much more effective “engine” of evolution – and a weapon in the merciless struggle for survival – rather than somatic potentialities.

The psyche is very complex. Its essence is distal to measurable, countable and “tangible” reality, hence empirical methods – firmly rooted in reality – cannot be as efficient in psychology as in physics. If they are effective at all… This is why R. Dawkins stated that “careful inference can be more reliable than actual observation, however strongly our intuition protests at admitting it” [25]. In fact, one might add that this statement is rather timid because “careful inference” is the only path leading towards theory and science creation.

Both passive purposefulness and active intentionality are strongly influenced by previous the experiences of living beings, at first only in phylogeny, later also in ontogeny. As a result, both kinds of anticipation became not liable to simple mathematical description. The latter might be regarded as “mechanical logic”, releasing a scientist from the necessity of arduous thinking. In physics and mathematics it is indeed efficient and productive. The discoveries of the Higgs’ boson [26] and gravitational waves [27] may be regarded as two recent brilliant examples of such “mathematical productivity”. The construction of the former has been invented on the basis of mathematical calculations by P. Higgs in 1964, the latter – by A. Einstein in 1916. Higgs’s boson waited
for the discovery of phenomena coherent with them for half a century; Einstein’s gravitational waves – a century.

Incidentally: here, the term “confirmation” has not been used. Theory is a highly abstract construct, where-as tangible reality makes up our natural environment. There are no direct and obvious relations between facts and theory, as well as between theory and applications. Already in the 18th century I. Kant stated that “general truths … must be independent of experience, – clear and certain by themselves” [28]. Also A. Einstein stated that “there is no way from experience to the construction of a theory” [29]. More recently the physicist A. Sta-ruskiewicz argued that the “mathematical theorems are valid on the strength of proof, and not by observations” [30; transl. WP]. Cybernetician M. Mazur argued:

In theory nothing may be justified with empirical knowledge. The theory, in which even one evidential link is taken from empirical knowledge (e.g., because in all known cases, it was observed that), is no theory at all [31].

Thus, each theory is by definition a simplification, and its scope of applicability has to be inevitably limited. M. Heller wrote:

All the successes of modern sciences – as all the other successes as well – are based on the idea of self-limiting. To achieve anything, it is necessary to give up many other things. Contemporary sciences have found their identity and immediately started their triumphant march through the series of simply unbelievable successes only when they resigned from putting questions that they were not able to answer [32; transl. WP].

Very significant is also another statement by M. Heller:

It is almost regularity in the history of physics that the mathematical structure of a given theory becomes known in full only when this theory has already been replaced with a new one [32; transl. WP].

Accordingly, on the basis of observations or experiments, it is possible merely to determine the limits of applicability of a given theory, but not its correctness. Already in the seventeenth century, B. Pascal remarked that “contradiction is not a sign of falsity, nor the lack of contradiction a sign of truth” [33]. Hence, if a scientist discovers a phenomenon not coherent with the already existing theory, it does not mean that the theory is false, but that – as it is always a simplification – either the empirical methodology is not precise enough or the phenomena under consideration remain in a region stretching outside the field of applicability of that theory. For example, quantum physics did not invalidate the Newtonian rules in the part of the universe accessible to our senses.

While admitting that Petryński proved that Miller’s number $7 \pm 2$ is wrong, it would be very seductive to paint an image of Petryński, with his hands crossed, trampling over the corpse of George A. Miller and heralding to the whole world: “I’ve just debunked the theory of the Great Miller!” However, such an image would be rather coherent with the Guinness Book of Records, but ridiculous while seen from the perspective of science. Because science should sound like a symphony, where various instruments cooperate with each other, and not like a sport, in which one athlete tries to prove his/her superiority over an opponent. In science, rivalry – though indeed useful to some extent – is not as essential as cooperation. Only the latter makes the essence of a system and its most precious product: the unpredictable, qualitatively new, progress bringing system effects.

Hence, a theory is an abstract mental construct. It may be – though it is not necessary – parallel to respective phenomena and processes, but it cannot be regarded as a perfect mirroring of reality in the mind. Moreover, even if a given theory may mirror the reality, more or less truly, nobody knows where and when the paths of theory and reality will part from each other. For the subject matter of motor control – unlike that of, e.g., physics – very abstract and distal to tangible reality are the relations between theory and what is being observed.

The possible shortcomings of the mathematical method of research and explanation had already been discerned in the 19th century by W. Thomson (Lord Kelvin) and P.G. Tait, who argued:

Nothing can be more fatal to progress than a too confident reliance on mathematical symbols; for the student is only too apt to take the easier course, and consider the formula not the fact as the physical reality [34].

So, the invention of any phenomena or processes in biology on the basis of mathematical operations seems to be almost impossible. Here, there is no “mechanical logic”, and independent reasoning is absolutely necessary. All this might be supported by the following statement of the outstanding mathematician I.M. Gelfand: “Application of contemporary mathematics and physics to biology is a dead-end. … Do not waste time on mathematics – think” [35]. Also, in A. Einstein’s cabinet at Princeton there was an inscription (words by sociologist W.B. Cameron):

Not everything that counts can be counted, and not everything that can be counted counts.

By the way: This statement might be regarded as a specific formulation of the famous incompleteness theorem by K. Gödel, who in the 1930s made the turning point in development of mathematics.

Contemporary mathematician I.N. Stewart also argues:
Biology requires – indeed demands – entirely new mathematical concepts and techniques, and it raises new and fascinating problems for mathematical research [36]. Nevertheless, the seductive charm of mathematics made many scientists use (allegedly) the “Queen of the Sciences” in disciplines, where it is obviously irrelevant. The outstanding mathematician R. Thom argued:

Teaching mathematics is nowadays nearly useless in the understanding of the majority of scientific disciplines, so mathematicalization of the majority of sciences is completely unnatural. It is a specific trick, originated in fashion for … countability of everything, as well as in the existence of computers. It is that kind of mathematicalization which does not contribute to understanding the phenomena which it describes [3; transl. WP].

In such a situation, two streams of development appeared in science. The first is based on establishing the observable and measurable facts. B. Forscher [37] compared them to bricks. The other consists in creation of theories, being in fact, the very ‘salt’ of science. Forscher compared them to edifices. And, as he had already in 1963 remarked, in science there are many brick producers, and few edifice builders. However, as H. Poincaré already remarked long ago, “an accumulation of facts is no more science than a pile of bricks is a house”.

The idea of the “black box”, often used in science as a justification of the work non-scientific in its essence, evokes a more general reflection. Each genuine scientist has to dispose of childish longing for fairytales, i.e., something not existing in reality. In the behavioristic paradigm, such a “genie in a bottle” was the “black box”, and nowadays, e.g., “self-organization”. On a wider scale, indeterminism may also be categorized as such a “genie in a bottle”. Mathematician R. Duda argued:

The world of physics is deterministic, and indeterminism in its description results from our limited cognitive potentialities… While looking at science development from a historical perspective, the deterministic explanation of phenomena always makes up the superior goal [38; transl. WP].

To sum up, one might compare – from the system-theoretical perspective – the following factors of physical body, biological “hardware”, and mental “software”: attitude towards future, anticipation and active consciousness (Table 1).

Table 1. Specificity of physical body, biological organism and mental psyche.

<table>
<thead>
<tr>
<th></th>
<th>Physical body</th>
<th>Organism: biological “hardware”</th>
<th>Psyche: mental “software”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude towards future</td>
<td>None</td>
<td>Shaped by evolution</td>
<td>Shaped by evolution and a given individual</td>
</tr>
<tr>
<td>Anticipation</td>
<td>None</td>
<td>Passive</td>
<td>Active</td>
</tr>
<tr>
<td>Consciousness</td>
<td>None</td>
<td>None</td>
<td>Crucial</td>
</tr>
</tbody>
</table>

Passive anticipation may be exemplified by the cellular membrane, which – unlike a physical body – somehow ‘knows’ what it may introduce into the cell and what has to be pumped out of it. In passing: in this context, active attention might be regarded as the main manifestation of the self [19].

Miller’s “magical number 7±2”

According to the behavioristic paradigm, the only observable behavior may make a basis for creation of science. Accordingly, the mind and psyche reside in the “black box”. This was very categorically expressed by M. Mazur who stated that “mechanism of psyche, as being inaccessible for observation, remains beyond the field of psychology” [31]. In fact, the same in its essence statement one might find in the paper by J.B. Watson [8].

However, if we admit that science arises on the basis of inference – and not measuring, counting and observing – then the phenomena and processes inside the “black box” become possible to scientific penetrations. So, the great service of G.A. Miller was that he dared to look into the ostensibly not analyzable “black box”. In his famous work, he stated:

Since the memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply by building larger and larger chunks …[14].

The quoted work by Miller is one of the most influential papers in psychology [15, 17]. N. Cowan defines the term “chunk” as follows:

I will define the term chunk as a collection of concepts that have strong associations to one another and much weaker associations to other chunks concurrently in use [15].

Thus, the chunk might be compared to an “intellectual molecule”. Moreover, apart from internal coherence, it may be “intellectually ionized” and, as a result, especially liable to join the other selected chunks. Also J.M. Morawski maintained:
More meticulous experiments show that even with smoothly changing input stimulus and inertia of the object of control, the control reaction of a human-operator is being characterized by some discontinuity [39].

The internal structure of a chunk may be diverse. A.R. Damasio argued:

Each sensory system appears equipped to provide its own local attention and working-memory devices [40].

For example, H.P. Grice argued:

Pains are not greatly variegated, except in intensity and location. Smells are [41].

Here, one comes across the issue of various modalities of information (and its chunks). Each modality disposes of its “own” code of information processing and the mechanism of such processing, i.e., the logic. It was not discussed in detail by Miller, but it clearly results from Bernstein’s five-level movement construction system, published nine years earlier — unfortunately, only in Russian — than Miller’s famous paper. In particular, Grice’s pain may be assigned to Bernstein’s B-level.

However, one might say that — roughly — Miller analyzed the psyche as an independent phenomenon, and not as a part of a much more extensive system consisting of mind, body and environment. He worked on the assumption that information in the human mind is divided into chunks. Next, Miller put forward the question of how many chunks the human mind is able to simultaneously process. He argued that the maximum number (determined rather arbitrarily) amounts to 7±2. Nevertheless, he argued:

Then I can say that the number of bits of information is constant for absolute judgment and the number of chunks of information is constant for immediate memory. The span of immediate memory seems to be almost independent of the number of bits per chunk, at least over the range that has been examined to date. The contrast of the terms bit and chunk also serves to highlight the fact that we are not very definite about what constitutes a chunk of information [14].

By the way: Already in 1945, A. Einstein wrote about similar phenomenon, which he termed “Enge des Bewusstseins” (“Narrowness of Consciousness”) [42]. However, he did not define the term “chunk”, and, all the more, did not try to determine or guess the number of chunks which the human mind is able to process at once. It is worth noting that “the number of bits per chunk” cannot be identified with what may be termed as “chunk modality” (haptic, visual, verbal, etc.). Nevertheless, concluding his article, Miller stated:

In fact, I feel that my story here must stop just as it begins to get really interesting [14].

Following this way of reasoning, some other scientists determined another number of the information chunks which a human is able to process simultaneously [16, 43]. However, in this respect, also important is the modality of a given chunk and the level of stress, which brings about the phenomenon of attention narrowing [44, 45]. Accordingly, the clear determination of the strict number of information chunks which a human individual is able to process simultaneously seems hardly possible (and reasonable).

In general, one might state that Miller perceived consciousness from the “citius, altius, fortius” sport perspective. However, the nature does not break records; nature solves tasks at the lowest cost possible. Let us exemplify this with the following situation:

During a sailing race of old-timers, when a yacht has to tack around the buoy, the skipper has to pay attention to:

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Number of chunks</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Two flying jib sheets</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2.</td>
<td>Two jib sheets</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Mainsheet</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>4.</td>
<td>Two running backstays</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>5.</td>
<td>Helm</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>6.</td>
<td>Mizzensheet</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>7.</td>
<td>Course relative to buoy</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>8.</td>
<td>Two opponents in the area</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>9.</td>
<td>Wind (possible shift)</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>10.</td>
<td>Waves</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>11.</td>
<td>Currents, stream, tidal stream</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>12.</td>
<td>General navigation</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>
So, the total sum of attention demanding items exceeds the maximum number determined by Miller, which equals 9. What strategy has to be applied, then, to solve such a task?

Theoretically, there are two possible solutions:
1. To extend the scope of attention.
2. To apply sequencing of particular sub-tasks, and, as a result, to reduce the number of information chunks processed simultaneously.

Somewhere in the background of the Miller’s concept looms the former. On the other hand, the latter makes a crucial component of N.A. Bernstein’s theory.

By the way: It seems that what J.J. Gibson termed as “education of attention” [46] is coherent with the latter rather and not with the former.

**Bernstein’s reduction of degrees of freedom**

Bernstein’s degrees of freedom may be regarded – roughly – as equivalents of Miller’s chunks of information. Roughly – because a chunk may be free, i.e., independent of any other chunk. On the other hand, the term “degree of freedom” comes from theoretical mechanics and denotes a parameter which has to be determined to describe the movement of a physical system. A definite number of freedom degrees equals the number of parameters necessary for complete description of such a movement. Hence, unlike a chunk, the degree of freedom must have potentiality to make a system along with other degrees of freedom.

It is worth noting that Bernstein had profound physical and mathematical knowledge, although not confirmed with official diplomas. He also spoke 8 languages (including Polish), played the piano and drew pictures excellently [47].

In classical mechanics, degree of freedom is used for the description of movement [48]. For example, a free body has six degrees of freedom: three translations along x, y and z axes, and three rotations around these axes. All the possible movements may be produced as a combination of them.

In Bernstein’s theory, the notion of degree of freedom has to be extended. It should concern not only physiological movements, but also the quantities corresponding to them at A, B, C, D, and E levels of the modalities’ ladder [49]. So, the “mental degrees of freedom” concern not the observable movements themselves, but the abstract information processes – of various modalities – underlying them.

In general, Bernstein’s way of thinking ran in a direction precisely opposite to that of Miller. Bernstein considered how to reduce the number of degrees of freedom to gain the manageability of a specific system. So, the system becomes controllable when the number of Miller’s chunks meets the Bernstein’s number of degrees of freedom. In such a sense, the theories of both the Giants – though seeing the same reality from opposite directions – should be regarded as complementing each other rather than competing with each other.

**One parameter control – Equilibrium Point Hypothesis**

The Equilibrium Point Hypothesis was created by A.G. Feldman. Nowadays, one of its most outstanding promoters is M.L. Latash [35, 50, 51].

The main idea is simple and bases – roughly – on the Newtonian principle that the final position of a working organ needs equilibrium of all forces and torques involved. However, if one takes such a final position as an attractor – which draws the processes in progress to a desired solution – then the point is not a static equilibrium position itself, but the dynamic process of achieving it. Moreover, in human motor operation, the physical equilibrium in an environment has to be somehow evoked by physiological and psychological processes. Hence, the postulated attractors may be positioned at various “rungs” of the modalities’ ladder.

A specific “generalized attractor” may be regarded as a full “prescription” for solving a motor task assigned to a particular rung [49]. The types of motor operations and their internal patterns (“generalized attractors”) are shown in Table 3.

It is worth noting that neither D- nor E-level has its “own” sensory organs. Detaching information processing from current sensory experiences was the inevitable

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**Table 3.** The modalities’ ladder: motor operations and their internal patterns.

<table>
<thead>
<tr>
<th>Level</th>
<th>Motor operation</th>
<th>Motor operation pattern</th>
<th>Main information processing mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Reflex</td>
<td>Coupling</td>
<td>Sensory: proprioception</td>
</tr>
<tr>
<td>B</td>
<td>Automatism</td>
<td>Template</td>
<td>Sensory: contactception</td>
</tr>
<tr>
<td>C</td>
<td>Habit</td>
<td>Scenario</td>
<td>Sensory: teleception</td>
</tr>
<tr>
<td>D</td>
<td>Performance</td>
<td>Program</td>
<td>Metasensory: verbal</td>
</tr>
<tr>
<td>E</td>
<td>-</td>
<td>Idea</td>
<td>Metasensory: symbolic</td>
</tr>
</tbody>
</table>
price which had to be paid for extension of the temporal scale of such processing beyond the limits marked by sensory organ capabilities, e.g., extending the time axis of information processing far into the past and future. At D-level (“common reason level”), the abstract mental representations mirror reality quite truly, hence, it may manage possible performances, patterns of which go far beyond immediate sensory control. On the contrary, at E-level (“fantasy level”), all the constraints of reality are rejected, hence, they cannot control any real performance. Nevertheless, the most advanced creativity “resides” at that level.

The general arrangement of possible “one-parameter” controlling chunks at various levels of the modalities’ ladder may be presented as the “descending firework” [52]. This is shown in Figure 2.

The higher level, the more profound but, at the same time, slower in information processing. Therefore, in this respect, there are two competing factors determining application of a particular motor operation pattern:
1. The necessary flexibility and depth of information processing.
2. The temporal conditions.

Accordingly, if in a given situation the temporal demands make it impossible for information processing of necessary depth, then the decision has to be made swiftly and due to this, such a decision is often far from optimal. This is concisely expressed by the English proverb “haste makes waste”.

**Conclusions**

To sum up, one might assign the following questions to the scientists, whom we invited to the ceremonial intellectual dinner:

G.A. Miller: What is the maximum number of chunks manageable by the human mind?

N.A. Bernstein: How do we reduce the freedom degrees in human motor operation to make it controllable?

A.G. Feldman: How do we reduce the number of information chunks necessary to achieve the (multimodal—WP) equilibrium to one?

None of these questions can be answered on a methodological basis, indeed. A fairly mechanical analysis of the experimental data would not be sufficient.

The great physicist N. Bohr stated:

*We must be clear that when it comes to atoms, language can be used only as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images and establishing mental connections* [53].

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**Figure 2.** The “descending firework principle”. An operation pattern (controlling chunk) from higher level “tows” the lower ones assigned to it without attention engagement [52].
The outstanding engineer, biomechanist and bio-cybernetician J.M. Morawski – who also has profound musical education – wrote a treatise about the very essence of human genius and compared the two Giants: I. Newton and J.S. Bach [54]. He claims that under other circumstances, Bach would become a brilliant physicist, and Newton an outstanding composer. In other words, the musical and physical genius are – probably – somehow symmetrical to each other, or at least they have common roots.

In Bach’s masterpieces, dialogs of particular instruments are very characteristic, either with each other or with the whole orchestra. This is just one of the phenomena that make the Bach’s music especially interesting and intriguing – simple and brilliant.

Accordingly, while listening attentively to the Giants and distilling a specific dialog in their conversation, one might unveil many valuable scientific ideas. Moreover, they should not be treated as unshakeable monuments. The history of physics – especially at the break of the 19th and 20th century, when quantum physics was born – shows that not debunking the monuments, but the creative interpretation (or re-interpretation) of the ideas of Giants bears the real progress. In short, great achievements of old Giants do not release the contemporary scientists from thinking. Hence, a virtual evening with N.A. Bernstein, G.A. Miller and A.G. Feldman might result – completely without additional costs – in enriching our scientific image of the world. Such a purely mental operation may be much more instructive than the rough knowledge “mined” from expensive, boring experimental studies. Moreover, it seems hardly possible that real progress in science will be attributed to a scientist who efficiently uses a computer, spectrometer or electron microscope, indeed, but who does not know “Winnie the Pooh” or “Alice’s Adventures in Wonderland”.

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FORCE ASYMMETRY INDICATOR IN THE ASSESSMENT OF MAINTAINING HUMAN BODY BALANCE IN AN UPRIGHT POSITION

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Keywords: body balance, erect posture, symmetry, asymmetry, strength.

ABSTRACT

Introduction. Most studies dealing with the process of maintaining the body balance in erect posture are concerned with the motor mechanisms ensuring the safeness of the process. A relatively small number of works analyse the changes in values of the ground reaction forces (i.e. the resultant and its components) in response to the pressure of the left and right foot occurring during this process, and the possibility of utilising them to evaluate its various aspects (repeatability, laterality, etc.). These problems seem worth explaining, an attempt at which was made in the present study.

Aim of the study. To examine the possibility of using the direct measurements of the ground reaction force components (in response to right and left foot pressure) as a function of time, along with the force asymmetry indicator (FAI) created from the measurement values, to assess the laterality and symmetry of functioning of feet while performing weight transmission and balancing functions when maintaining erect posture. An additional decision was made to check if repeatability of these activities occurs.

Material and methods. The study involved 82 persons (out of whom 31 were women and 51 were men). The study consisted of recording changes of ground reaction forces during three consecutive 15-seconds’ attempts at maintaining body balance in an upright position. With the use of two piezoelectric platforms, the measurements and recording were made for the three force components: vertical, horizontal (lateral) and horizontal (anterior-posterior direction). The results of the synchronised time measurements of the forces in relation to right and left foot were used to construct the force asymmetry indicator (FAI), which was subjected to multivariate statistical analysis.

Results. The foot pressure causes different rates of ground reaction forces for all the directions of its components when maintaining body balance in erect posture. The largest differences occurred in the transfer of body weight forwards and backwards, and only slight differences occurred for transfer to the sides and along the up-down direction. Values and signs of the asymmetry indicator show that for the majority of respondents, the left foot is the dominant one for the function of weight transmission (the up-down direction), whereas it is the right foot that takes over the function of balancing posture (positive values of the asymmetry indicator for front-back and left-right directions). The comparison of mean values of the asymmetry indicator in three consecutive tests indicates repeatability of balance mechanisms in subsequent studies.

Conclusions. The proposed asymmetry indicator may serve to assess laterality of action of the lower limbs (feet) in the process of maintaining body balance in erect posture; the assessment can be done on the basis of recording ground reaction forces for different directions of the forces, by pointing to the dominance of one of the lower limbs in fulfilling the weight transmission and balancing functions.
Introduction

Maintaining erect, bipedal posture is an innate genetic basis of human motor development. Maintaining body balance in this position is governed by complex, as of yet not exactly defined mechanisms. So far, studies on maintaining balance relate mainly to motor mechanisms securing the process [1,2,3,4]. Most of the studies’ authors had aimed to answer the following question: how does human act in order to prevent falls and keep the body upright? Most often, the answer was sought by means of research based on the analysis of movement of the point of application of the ground reaction force resultant (COP, centre of pressure) depending on the displacement of the application of gravity (COM, centre of mass). The fractal dimension used as a measure of the state of chaos calculated from the course of these two points was introduced into the assessment of the stability of the human body by Blaszczyk and Klonowski [5]. Flis et al. [6] used the autoregressive model to describe the maintenance of balance in adults. Kuczyński [7] proposed a model of second-order autoregression for highlighting in the course of COP the movements that balance body deflexion, after subtracting the changes in placement of the body’s centre of mass from the course recorded.

The literature concerned with maintaining body balance contains relatively few reports focusing directly on the change of the magnitude of the forces in effect, and yet it is these forces that contribute to performing every physical activity. The most relevant are the values of forces: the resultant and its components (vertical and horizontal), ground reaction, which are equivalent to the force of feet putting pressure on them. A considerable part of the research focuses on the mechanism of force deficiency (e.g. the difference between the moments of muscle forces having effect on the left and right knee joint) and is usable only as a description of a single motor event (as opposed to a process performed in time). In addition, the mechanism of force deficiency is in itself not yet known: the phenomenon is ever-changing and unobservable under experimental conditions [8,9,10,11]. The explanation of its occurrence is looked after in the processes of neurological inhibition and in stimulating bilateral contractions [12].

One of the key issues related to the assessment of the body stability is the assessment of the asymmetry of the lower limbs’ weight transmission function. Therefore, a question often appears whether a person keeping body balance in an upright position uses both feet equally, causing the same ground reaction forces. The answer to this question is not clear since feet not only carry the entire weight of the body, but also perform various actions to compensate for the sway that can be called balancing actions. The question, then, is this: which limb is responsible for weight transmission, and which one only supports balancing of the body? Research conducted using COP oscillation for this assessment indicates the functional dominance of the right lower limb (associated with greater amplitude of movement within the right ankle joint as opposed to the left). Greater amplitude of movement of the right ankle joint while standing may constitute evidence of the readiness of the right limb for intended movement (e.g. a step), and thus demonstrates the functional (motor) dominance of the right lower limb; the left lower limb can be said to be dominating the weight transmission function [13]. Are the same conditions observable in the recording of the magnitude of ground reaction force components (the vertical one and the horizontal ones), and are they corresponding to the pressure of the right and left foot to the ground in a function of time? Because it was indeed assumed that the recording of force in a time interval reflects the movement of transferring weight from one foot to another in a prolonged motor operation (and keeping erect posture can be considered one). The analysis of changes in magnitude of these forces brings us closer to the understanding of mechanisms regulating, for instance, the precision of balance-keeping movements.

Another very important problem with body stability studies utilising the COP and COM relationships is their reproducibility (even with the use of the same methods and equipment). Brouwer et al. [14] state explicitly that the process of maintaining balance is not repeated for the same adult in consecutive attempts. Is that what happens in the case of analysis based on the direct assessment of the magnitude of ground reaction force resulting from the pressure of feet while maintaining the balance of the body in an upright position? These problems seem to be worthy of an explanation, an attempt at which was made in this work.

Aim of the Study

To explore the possibility of using direct measurements of the ground reaction force components in relation with right and left foot pressure in a function of time, as well as the force asymmetry indicator (FAI), to assess the laterality and symmetry of feet functioning (weight transmission and balancing while keeping erect posture). Additionally, a decision was made to check whether repeatability of these actions takes place.

Material and methods

The study included 82 patients (31 women and 51 men) aged 14 - 55 years (x = 22.56 ± 1.81). Average body height of the subjects was 181.69 ± 6.39 cm, and
average weight was 78.73 ± 10.71 kg. In order to provide a broader spectrum of the population, both practicing athletes and people not engaging in sporting activity participated in the study.

The study was performed at a certified Laboratory, i.e. the Biomechanical Analysis Laboratory of the University School of Physical Education in Wroclaw (certificate PN-EN ISO 9001: 2001). The study involved recording of changes of the ground reaction force in relation to the feet pressure while maintaining the balance of the body in an upright position. Subjects were standing freely on two piezoelectric platforms (600 x 400, the Kistler Type 9286B, Kistler Instruments AG, Winterthur, Switzerland) operating on the BioWare 4 software (by Kistler, Corp.); additional hardware for measuring ground reaction forces was also utilised. The platforms enable measurements of force in the range of -10 kN to 20 kN. Force was measured with the use of four piezoelectric sensors arranged at the corners of the platform. Before measurements were performed, the platforms were calibrated, and BTS Smart system ensured the accuracy and reliability of measurements. There was a separate platform for either foot. The feet were set straight (without any rotation of the ankle joint) at a distance of 30 cm. Upper limbs were let loose along the trunk. In a single trial, the subject was asked to maintain a fixed posture for approx. 25 sec. Ground reaction forces were measured for 15 seconds approximately 10 seconds after each trial had started. The test was repeated three times - one after another, without changing the setting of the feet. Recording of the ground reaction to the feet pressure was made for the three force components: Fx - horizontal force in the frontal plane (lateral direction); Fy - horizontal force in the sagittal plane (anterior-posterior direction); Fz - vertical force. Force values were calculated relative to the body weight of the subject and expressed divided into left and right foot. The sampling frequency during the measurements was 50 Hz. The record of ground reaction forces of the two platforms was synchronized in time on a PC computer. An exemplary record of performance in a single subject for vertical force in respect to the right (FzR) and left foot (FzL) are shown in Figure 1.

For the evaluation of the asymmetry between the feet, on the basis of changes in the magnitude of ground reaction forces, the differences for each measurement sample between the ground reaction force value related to right and left foot pressure (FzR - FzL) were used. The results of the differences as a function of time (t) (duration of the test) for the force in the vertical direction are shown on the graph (Fig. 2).

For such a resulting signal, a mean value in a time series was calculated and called the forces asymmetry indicator (FAI).

Such calculations were performed for the signals of force components operating in three directions (x, y, z). Depending on the sign of the FAI value (negative or positive) it FAI assumed that this variable determines the symmetry or laterality combined with the domination of one another.

Figure 1. An example, individual record of changes in the value of the vertical component reaction force of the surface to the right and left foot pressure as a function of time; Fz for the right foot (black line) and left foot (the red line)
lower limb (foot) over the other in the process of maintaining body balance (carrying weight and the occurrence of balancing movements during the measurement. 

The results were verified for normal distribution with the use of Shapiro-Wilk test; then, statistical calculations were carried out determining the means and standard deviations in the whole group, as well as for groups of women and men separately. Comparisons of mean values of FAI in subsequent studies and between sexes were made using analysis of variance with repetition. The least significant difference test was used as the post-hoc test. In the assessment of the relationship between the variables examined, Pearson’s simple correlation was used. Statistically significant were considered the differences and correlations at $\alpha = 0.05$ ($p \leq 0.05$). All calculations were performed using the STATISTICA 9 program.

Results

Testing distribution of variables pointed to its normality. Analysis of variance did not show any significant differences in subsequent studies between the studied inter-sexual variables. Therefore, it is assumed that further analysis of the results of the research can be conducted on the full number of the 82 surveyed people as a homogeneous group. 

From the course of ground reaction force as a function of time, minimum and maximum values of the resultant force and its components were selected. For the whole group of respondents, in three attempts, these values fall in the following ranges:

- the resultant force of the left foot - 171.63-610.50 N; right - 201.92-624.54 N,
- the vertical force (up-down)of the left foot - 170.91-608.85 N; right - 201.15-623.44 N,
- the horizontal force (left-right)of the left foot -25.05-49.91 N; right - 21.75-48.25 N,
- the horizontal force (front-rear)of the left foot - 25.56-30.25 N; right - 9.71-8.82 N.

Ground reaction forces in response to the right and left foot pressure differ slightly for particular planes. The range of the ground reaction forces in response to the right foot pressure is smaller than for the left foot: for the direction up-down 15.65 [N], for left-right 4.96 [N] and for front-rear 37.28 [N].

Values and symbols of FAI calculated for three consecutive 15-seconds’ attempts indicate that for the majority of people, the dominant in the function of supporting body weight (direction up-down) is the left foot (Table. 1), whereas the right foot is responsible for balancing the body (positive FAI values for front-rear and left-right directions). Comparison of mean FAI values of successive trials indicates that the results of the first, second and third trial do not differ significantly ($p > 0.05$) (Table. 2). It can therefore be said that the standard difference in ground reaction forces to pressure of the right and left foot marked as function of time is repeated in subsequent studies.
Table 1. Statistical characteristics of the values of feet pressure asymmetry on the ground (on the basis of FAI) in the three directions of force (z – vertical, x – lateral, y - anterior-posterior) in three consecutive trials in the studied group (N = 82)

<table>
<thead>
<tr>
<th>FAI</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>SD</td>
<td>Min</td>
</tr>
<tr>
<td>z</td>
<td>-2.32</td>
<td>37.22</td>
<td>-102.27</td>
</tr>
<tr>
<td>x</td>
<td>1.11</td>
<td>2.25</td>
<td>-4.18</td>
</tr>
<tr>
<td>y</td>
<td>0.68</td>
<td>7.72</td>
<td>-27.37</td>
</tr>
</tbody>
</table>

Table 2. Comparison of average FAI values in three trials in the studied group (N=82)

<table>
<thead>
<tr>
<th>FAI</th>
<th>Repetitive effect</th>
<th>Probabilities for post-hoc tests, NIR test, p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>z</td>
<td>0.15</td>
<td>0.8582</td>
</tr>
<tr>
<td>x</td>
<td>0.18</td>
<td>0.8373</td>
</tr>
<tr>
<td>y</td>
<td>0.34</td>
<td>0.7140</td>
</tr>
</tbody>
</table>

Table 3. Correlations between FAI on x, y, z directions during three trials in the studied group (N=82)

<table>
<thead>
<tr>
<th>Direction of forces</th>
<th>FAI correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
</tr>
<tr>
<td>x-z</td>
<td>-0.27</td>
</tr>
<tr>
<td>x-y</td>
<td>-0.03</td>
</tr>
<tr>
<td>y-z</td>
<td>-0.24</td>
</tr>
</tbody>
</table>

Significant correlations at probability of p ≤ 0.05 are in bold

Analysis of correlation coefficients that occur between the FAI for the three directions of the ground reaction forces in the study group enables a conclusion that statistically significant associations were between FAI of force vertical component and FAI of forces horizontal components (both in sagittal and frontal planes) in all three trials (Table. 3). Negative correlation marks indicate that the higher the FAI of strength of the vertical component, the lower the FAI of the force horizontal components.

Discussion

The abilities of humans to manipulate limbs are extraordinary. Obviously they are much greater in the case of the upper limbs than in the lower limbs. This is due to the limitations resulting from having to carry the body weight by the latter; for the primary function of the lower limb is weight transmission. Supporting body weight is connected with maintaining erect posture [15], which involves stabilising the body in standing and perform in locomotor movements such as walking, running or jumping. While knowing that two-thirds of the body weight is situated above one third of the body height, the challenges standing before the body posture regulation mechanism should be taken into consideration. Winter et al. [16] emphasise that this is a mechanism that should perform with great precision throughout the whole life. Unfortunately, it is not the case. The body is aging over the years, a symptom of which are disorders of the body posture regulation mechanisms [17,18]. Statistical data indicate alarming, constant increase in the number of medical events, including deaths due to fall. According to the World Health Organization [19] falls are the cause of 20-30% of mild injuries, 3-5% of hospitalizations, 5% of deaths in people over 75 years of age. Problems with balance can be a harbinger of other diseases, dangerous to human health. As life expectancy of humans is still growing, pathologies of these mechanisms force scientists and physicians to take multi-faceted research on maintaining body balance to gain better understanding of the mechanisms regulating this process.

It seems that the mechanism for controlling the maintenance of an upright posture should aim to send the same signals to the muscles of both lower limbs. In case of any differences between the values of pressure...
force exerted on the ground separately by right and left foot, it can be said that there is a specific manifestation of functional asymmetry while maintaining body balance in a standing position.

To study the distribution of pressure exerted by the body weight on the ground, the tensometric stabilometry is most commonly used. This method, however, has limited usefulness for the evaluation of postural stability, and not only in relation to the determination of the dynamic imbalance of the lower limbs [15,20]. The results of such studies are based mainly on the interpretation of the point of application of pressure force. The method is used to evaluate the asymmetry of the pressure force of the right and left foot only when the reaction force measurement takes place on two separate platforms. Using these devices, and on the basis of the record of COP (centre of pressure) course in function of time for the left and right leg, many measurements can be determined, including: variability, range of displacement of the COP, the speed of the displacement, the surface area designated by the pressure points of feet while standing. On this basis it is possible, however, only to identify symmetry and asymmetry of the kinematic indices [21]. Kuczyński [7] focused on the difference in the position of the centre of mass projection and the position of the point of the resultant force of the foot to the ground by proposing to develop stabilograms by means of a simple subtraction of measured signals (COM - COP). Other researchers have proposed various other indicators and indices to measure the laterality (asymmetry) of action of the lower limbs [21,22].

The use of two platforms to record synchronously the changes to the magnitude of ground reaction forces inspired a small number of researchers to analyse the results slightly differently. To determine the symmetry or laterality, they began to use directly the difference between the values of these forces. They determined, among other things, the differences between moments of force between lower limbs during operations performed simultaneously and separately by each of them in terms of statics and dynamics [23,24]. Brughelli et al. [25] used the differences of forces (in three directions) to compare healthy football players with those after injuries of the lower limbs; the interesting fact is that the research was conducted at submaximal speed and on a mechanical treadmill. The drawback of this approach is that both limbs do not work exactly at the same time. With the nonstationarity of human behaviour, it seems to be quite important.

The authors of this paper presented the results of research on the differences of ground reaction forces in regard to pressure of the right and left foot during the process of maintaining balance in erect posture in slightly different terms. With regard to human, they proposed a solution widely used in automation, especially in relation to technological and industrial processes, based on an analysis of changes in the volume of ground reaction forces, separately for the left and right foot, synchronised in function of time.

One of the basic assumptions of the analysis of the results of research in this paper is the proposal of the delimitation of activities related to the functions taken by feet while maintaining body balance in standing position: weight transmission - related to the choice of the lower limb to receive greater load while standing, and balancing, related to the display of pressure forces on the ground in order to minimise sway of the body. To assess the functional laterality a new, as of yet unused measure was proposed, determined as force of asymmetry indicator (FAI), which, depending on the sign determines the dominance of one of the feet in taking different functions (weight transmitting and balancing in the process of maintaining body balance in an upright position in a given period of time (resulting from the duration of the trial).

The results obtained indicated that in the test group it was the left foot that took over the weight transmission function more often (as indicated by negative values of FAI on the vertical direction of the force). Positive values of FAI in lateral and front-rear direction (i.e. on the plane in which the balancing movements take place) show that at the same time the right foot dominated the use of forces correcting sway of the body and preventing loss of balance (Table 1). No statistically significant differences in mean values of FAI between trials (Tab. 2) indicates that the mechanism is repeatable.

Correlation analysis between the values of FAI on different directions of forces indicates a significant relationship occurring between the asymmetry of forces developed in time for the vertical direction and both horizontal directions (lateral and front-rear) (Table 3). The symbol of the correlations indicates that the greater the asymmetry of the forces acting on the vertical direction, the lesser the asymmetry of the forces developed at the horizontal directions, which seems to imply that the more decisive role one lower limb starts to play in weight transmission, the lesser the balancing activity the second limb must demonstrate.

**Conclusions**

1. Pressure with feet evokes a different ground reaction force in all directions of its components while maintaining the balance of the body in an upright position. The largest difference occurred in the transfer of body weight forwards and backwards, and slight to the sides and in the up-down direction.
2. Negative symbols of the FAI asymmetry of forces on the vertical direction indicate that for the majority of respondents, the left foot prevailed in the function of weight transmission while the right foot had the leading role in balancing functions.

3. No statistically significant differences in mean values of FAI in subsequent trials indicates that the mechanism is repeatable.

4. The correlations between the values of FAI on different directions of the forces seem to indicate that the more decisive role in weight transmission one of the lower limbs plays, the less activity in the field of balancing must be performed by the second limb.

The proposed force asymmetry indicator (FAI) may serve as a tool to assess the laterality of action of the lower limbs (feet) in the process of maintaining the balance of the body in erect posture on the basis of recording of ground reaction forces for different directions of effect pointing to the dominance of one of them in fulfilling the weight transmission and balancing functions.

References


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Fax: +48 71 347 3149
Mobile: +48 608 820 397
Studies aim. The aim of the study was to examine the basic personality traits of athletes practicing sports disciplines of a different type of physical effort and training (high-speed, endurance and mixed) at a master level and to present the basic structures of behavior associated with the resulting personality profile.

Materials and Methods. The study included 47 athletes aged 23.5 ± 4.2 years, representing Poland at international competitions: 11 sprinters, 15 endurance sports athletes (triathletes and long-distance runners), 14 futsal players and 7 Olympic taekwondo athletes. In order to study the personality of the athletes, we used a Polish adaptation of the NEO-FFI questionnaire.

Results. Highly-trained sprinters, triathletes, long-distance runners, futsal players and taekwondo athletes did not differ significantly from each other in terms of personality traits. However, all of the athletes were characterized by a high level of conscientiousness, statistically higher compared with those from the standardization group. Sprinters, endurance athletes and futsal players demonstrated a significantly lower level on the scale of openness to experience compared to those from the standardization group. Endurance athletes and futsal players were characterized by lower levels of neuroticism and higher extraversion.

Conclusions. High-class athletes differ from the general population in terms of personality traits, which is why it is necessary to know their individual psychological characteristics in order to optimize training.

Introduction

Today, no one questions the need for constant cooperation of an athlete with a psychologist, not only in crisis situations, but above all on a daily basis in order to improve and maintain desired psychic dispositions, analogous to physical training. Relations between personality traits and successful athletes are the subject of interest of sports psychologists. The problem becomes even more interesting when athletes with similar physical capabilities and participating together in the same cycle of preparation reach different results in sports competitions. Some authors [1] claim that available studies indicate distinct personality differences between athletes and untrained persons, and show that personality is an important determinant of long-term success in sport [1, 2]. While others [3] indicate that the results of research on the differences between athletes and untrained people are inconsistent [see 4-11]. Similarly, the studies of athletes’ personality, depending on the type of sports, do not provide a clear answer regarding the desired personality profile of an athlete for a given type of sport [see 4, 7, 9, 10, 12].

In the course of training and sports competition, the behavior of athletes is determined by their basic personality traits, thus, in order to conduct effective training,
a coach should have knowledge of the personality profile of the athlete and the behavior structure resulting from it. In the work of a psychologist with athletes, firstly, it is most important to make a diagnosis by determining the relatively stable psychological traits of a athlete’s personality through testing [13, 14]. The psychologist’s goal is to determine the individual psychological profile. This is done so that the manner of work and communication between the athlete and the coach can be customized so measures to better mental and physical preparation for sportsmanship can be taken.

The aim of the study was to examine basic personality traits of athletes practicing selected sports at a championship level and to present the basic structures of behavior associated with the resulting personality profiles.

**Materials and Methods**

**Study participants**

We examined a group of 47 athletes (38 men and 9 women) aged 23.5 ± 4.2 years: 11 sprinters, 15 endurance sports athletes (triathletes, long-distance runners), 14 futsal players and 7 Olympic taekwondo athletes. They were international-level athletes according to the criteria of relevant sports associations: Olympians and Polish national team members, remaining under the supervision of experienced trainers, mostly national team coaches.

**Personality questionnaire**

In order to study the basic personality traits, the Polish adaptation of Costa and McCrae’s NEO-FFI personality questionnaire was used [13, 14]. The inventory is based on one of the most popular concepts, engaging personality in terms of five features called dimensions or factors, each of which includes six components: (i) neuroticism (anxiety, aggressive hostility, depression, impulsiveness, sensitivity and excessive self-criticism), (ii) extraversion (sociability, warmth, assertiveness, activity, search for sensations and emotions in a range of positive emotions), (iii) openness to experience (imagination, aesthetics, feelings, actions, ideas and values), (iv) agreeableness (trust, straightforwardness, altruism, tractability, modesty and willingness to tenderness a) and (v) conscientiousness (competence, willingness to maintain order, dutifulness, striving for achievement, self-discipline and prudence) that make up the five-factor personality model, the so-called Big Five. The questionnaire contains 60 items, twelve for each of the five dimensions. Each item is a statement demanding answers from the testee on a five-point scale from 1 to 5, where 1 is the answer - “strongly disagree” and 5 is - “strongly agree”.

**Data analysis**

Raw scores were converted into sten values, taking age and gender into consideration. The sten scale is a standard one containing 10 units (sten scores), normalized so that the average of the population reached 5.5 and the standard deviation of 2 [15]. The results within the range of 1 to 4 sten scores were treated as a low, 5 to 6 as medium, and from 7 to 10 as high. The average score of each group of athletes was referred to the average value of the tool’s scale. For comparisons, we used the t-test for one group. The effect value was calculated according to the Cohen formula, where the average of the scale was subtracted from the average result of the group and then divided by the standard deviation of the scale. A result of 0.8 meant a large effect size, 0.5 an average effect size and 0.2 a small effect size [16]. In order to compare each of the five personality factors depending on the sport discipline, the Kruskal-Wallis H test was used.

**Results**

Figure 1 presents the studied athletes’ personality structure. Descriptive statistics of five personality factors according to sten scores are presented in Table 1. The results showed that all groups of athletes were characterized by a high level, statistically higher compared to those from the standardization group, on the conscientiousness scale (sprinters: $t = 5.20; p < 0.01, ES = 1.12$; endurance athletes: $t = 5.58; p < 0.01; ES = 1.19$; futsal players: $t = 5.27; p < 0.01; ES = 0.90$; taekwondo athletes: $t = 4.24; p < 0.01; ES = 0.83$).

The sprinters, endurance athletes and futsal players demonstrated a significantly lower level on the openness to experience scale compared to those from the standardization group (sprinters: $t = -5.50; p < 0.01; ES = -0.84$; endurance athletes: $t = -4.77; p < 0.01; ES = -0.72$; futsal players: $t = 2.58; p < 0.05; ES = -0.54$).

The endurance athletes and futsal players were characterized by statistically lower levels of neuroticism (endurance athletes: $t = -2.66; p < 0.05; ES = -0.72$; futsal players: $t = -3.28; p < 0.01; ES = 0.82$) and statistically higher levels on the scale of extraversion (endurance athletes: $t = 3.96; p < 0.01; ES = 0.99$; futsal players: $t = 2.55; p < 0.05; ES = 0.82$) compared to those from the standardization group.

We revealed that there were no statistically significant differences between athletes of different disciplines related to personality traits. This was confirmed by the results of the Kruskal-Wallis test presented in Table 1. The highly-trained sprinters, triathletes, long-distance runners, futsal players or taekwondo athletes did not differ in terms of personality profile.
The personality of highly trained athletes in view of

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Fig. 1. Personality profiles of high-class athletes practicing the sprint, endurance sports (triathlon and long-distance running), taekwondo and futsal (according to sten scores).

Table 1. Mean and standard deviation of athletes’ personality traits (according to sten scores) and the results of the Kruskal-Wallis H test for each of the five personality factors indicating the differences between high-class players practicing the sprint, endurance sports (triathlon and long-distance running), taekwondo and futsal (n = 47).

<table>
<thead>
<tr>
<th>Athlete Type</th>
<th>Neuroticism</th>
<th>Extraversion</th>
<th>Openness to experience</th>
<th>Agreeableness</th>
<th>Conscientiousness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinters</td>
<td>4.1 ± 2.5</td>
<td>7.0 ± 2.2</td>
<td>3.8 ± 1.5</td>
<td>5.6 ± 2.5</td>
<td>7.7 ± 1.4</td>
</tr>
<tr>
<td>Endurance athletes</td>
<td>4.1 ± 2.1</td>
<td>7.5 ± 1.9</td>
<td>4.1 ± 1.2</td>
<td>5.5 ± 1.8</td>
<td>7.9 ± 1.6</td>
</tr>
<tr>
<td>Taekwondo athletes</td>
<td>5.1 ± 2.2</td>
<td>5.7 ± 2.0</td>
<td>4.9 ± 1.6</td>
<td>7.0 ± 1.6</td>
<td>7.7 ± 1.4</td>
</tr>
<tr>
<td>Futsal players</td>
<td>3.9 ± 1.9</td>
<td>7.1 ± 2.4</td>
<td>4.4 ± 1.6</td>
<td>5.9 ± 1.4</td>
<td>7.3 ± 1.3</td>
</tr>
<tr>
<td>H</td>
<td>1.35</td>
<td>3.58</td>
<td>3.01</td>
<td>3.14</td>
<td>1.49</td>
</tr>
<tr>
<td>p</td>
<td>0.72</td>
<td>0.31</td>
<td>0.39</td>
<td>0.37</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Key: H - Kruskal-Wallis test value; p – level of significance of Kruskal-Wallis test
Discussion

This study examined the basic personality traits of highly trained athletes in reference to general population. All athletes displayed a significantly higher level of conscientiousness on the conscientiousness scale, however, there were no differences as far as their diverse disciplines are concerned. Similar results were obtained by Malinauskas et al. [3], who compared both trained and untrained young men; Tomczak [17], who examined martial artists; and Allen et al. [4], who found that the competitors at the higher level (national and international) display higher levels of conscientiousness than those competing at a lower level (university and club). However, there was no difference in the level of conscientiousness among athletes practicing team, strength-speed and endurance sports [3]. On the other hand, Nia and Besharat [10] found a significantly higher score in terms of conscientiousness among athletes practicing individual sports compared to team sports players. People with a high result on the scale of conscientiousness exhibit strong will, are well organized and motivated to act, dutiful and committed, they strive for achievements and are persistent. They are characterized by a high level of ambition, competence and reliability, self-discipline and prudence; this is why the trait is desirable among people from whom success in sports is expected. They are usually also scrupulous, dutiful, punctual, hardworking, prudent and reliable, they tend to maintain order and are well organized, which is closely connected with their efficiency in some areas [14]. The more conscientious persons, thanks to clearly defined objectives, high motivation and a higher level of perseverance have a greater chance of achieving great sports results compared with those less conscientious [17]. These people tend to have a ‘road map’, often analyze their own behavior, they are better prepared [18] and use more effective coping strategies [19], all of which results in being better prepared, both technically and tactically. High intensity of this feature can also be connected with perfectionism and the possibility of overtraining.

Sprinters, endurance athletes and futsal players displayed significantly lower scores on the scale of openness to experience compared to the sample employed in the normalization process; the score of taekwondo athletes was average. However, no significant differences between the athletes of different disciplines were found. Past results of research on openness to experience conducted among athletes are not unambiguous. Malinauskas et al. [3] did not find any differences between trained and untrained men in terms of openness to experience. Kajtna et al. [20] compared high- and low-risk sports athletes with people not practicing any sports, and found that the highest openness scores were achieved by low-risk sports athletes, followed by high-risk sports athletes and people not engaging in any sporting activities. However, Dineen [6] and Allen et al. [4] showed that athletes engaging in individual sports were characterized by greater openness to experience, compared with team sports players, but no differences between them were found that would depend on their level of advancement in sports [4]. The results of Nia and Besharat [10] did not show any difference in terms of openness to experience between individual and team sports athletes. In the present study, the futsal players – that is, team sports players – received a lower score on the scale of openness to experience, compared to the normalization sample; the same was true for individual sports athletes, except for taekwondo athletes. This can be partly explained by the specificity of disciplines practiced by the subjects. People characterized by low openness to experience tend to choose traditional sports such as athletics or football, whereas practitioners of taekwondo, a sport by no means traditional in the Polish culture, received an average score on the scale of openness to experience. The low score on the scale of openness to experience is characteristic of a pragmatic and practical, traditional person, conservative in views and conventional in behavior, with a preference for socially accepted conduct. On the other hand, those open to experience look for experiences and value them positively, and show tolerance for novelty and cognitive curiosity [14].

In terms of extraversion, the results of sprinters, endurance athletes, and futsal players can be considered high, however, only in the last two groups the result was significantly higher compared to the normalization sample. There was no significant difference between disciplines. Tomczak [17] found significantly higher levels of extraversion in martial artists compared to the normalization sample, while Malinauskas et al. [3] found no differences between trained and untrained men in terms of personality traits; however, they found that team sports players (mainly basketball players) had a higher score on the scale of extraversion in comparison to endurance athletes (mainly long-distance runners and road cyclists). Similarly, Dineen [6] and Allen et al. [4] pointed to a lower level of extraversion among athletes in individual sports compared to team sports players but found no difference in the level of extraversion depending on their level of advancement in sports [4]. Different results were obtained by Nia and Besharat [10] who found no differences in extraversion between individual and team sports players. People with a high score on the scale of extraversion are sociable, affectionate, friendly, willing to have fun, upbeat, joyful and able to feel positive emotions, but also active, vigorous, with a high need to be busy and engaged, as well as enthusiastic and willing to seek stimulation [14]. Greater efficiency can be expected
of these people in situations in which social contacts and high energy are important, for example in team sports. Extraversion is also connected with the ability to process stimulation, which is useful in sports characterized by a need for such processing, and starting situations. These individuals remain less emotional in difficult situations, which gives them the ability to more effectively plan their actions, efficiently respond to the situation; it is also less likely for them to fall victim to disorganization of action [17].

Similarly, the results of research on the level of neuroticism among athletes are not unambiguous. The results of the present study, that is of research of high-class athletes show that sprinters, endurance athletes and futsal players received low scores on the neuroticism scale, but only endurance athletes and futsal players were significantly lower compared with the normalization sample. The taekwondo practitioners were characterized by average score in terms of neuroticism and did not differ from the population. Dineen [6] found that students not practicing sports presented significantly higher levels of neuroticism, compared to students actively practicing sports. The test results of Kajtna et al. [20] showed that the athletes participating in high-risk sports are characterized by the greatest emotional stability; after them come people not engaging in sports and then the athletes engaging in sports devoid of risk. Allen et al. [4] found that individual sports athletes are less neurotic in comparison to team sports players. In contrast, Malinauskas et al. [3] found no differences in neuroticism between men practicing team, endurance and strength-speed sports. Similarly, in the study by Nia and Besharat [10], athletes in individual and team sports did not differ in terms of this trait. Neuroticism is the dimension reflecting emotional stability or instability. People with low results on the scale of neuroticism are emotionally balanced and stable, calm, more confident, complacent and resistant, they cope well with difficult situations and stress, they experience less fear, tension and irritability [14] and deal with adversities better [18].

There were no significant differences in terms of agreeableness between sprinters, endurance athletes, futsal players and taekwondo athletes, and between all the former and the normalization sample. Sprinters, endurance athletes and futsal players presented an average score on the scale of agreeableness, while taekwondo practitioners achieved high scores, which may be associated with the specificity of the discipline. Similarly, no differences were found by Malinauskas et al. [3] between men practicing sports and those not engaging in sports, and between team sports players, strength-speed and endurance athletes. Allen et al. [4] also found no differences in terms of agreeableness between individual and team sports players but noticed higher levels on the scale of agreeableness among the athletes competing in national and international competitions compared to athletes on a lower level of contest. Nia and Besharat [10] found that team sports players are more conciliatory than individual sports athletes. Agreeableness describes the attitude to other people, which manifests itself in trust in others or lack thereof, sensitivity or indifference to other people’s affairs, but also in having a cooperative/competitive attitude. People with high agreeableness are nice to others, affectionate, gentle, modest, sincere, convinced that other people have honest intentions, are focused on the needs of others and willing to assist. Those with low agreeableness are self-centered, often manipulative, assess the intentions of others skeptically, they are convinced of their own superiority, are competitive and aggressive. This trait, however, cannot be directly evaluated, especially in sports. For example, in a team discipline, it can be assumed that agreeableness is a trait helpful in achieving success for the whole team, but in individual sports, the struggle for one’s own interests may prove more adaptive than the tendency to withdraw and defer [14].

Conclusions

The highly-trained athletes differ from the population in terms of personality profile. Therefore, it is necessary to recognize their individual psychological features in order to optimize the workout.

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FUNCTIONAL MOVEMENT SCREEN AS A TOOL FOR FUNCTIONAL EVALUATION AND PREDICTION OF THE RISK OF INJURY AMONG FLOORBALL ATHLETES

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Keywords: FMS, floorball, risk of injury

Abstract

Aim: An attempt to verify the disorders in fundamental movement patterns occurring in young floorball players and the relationship between the observed disorders and the occurrence of injuries.

Material and methods: The study included 23 high-performance male floorball players, ranging in age from 16 to 19 years (mean age 18 years). To evaluate the movement patterns, Functional Movement Screen (FMS) was used. The analysis used the total score of the test and the results of each of the 7 motor tasks. The characteristics of the athletes' injuries were obtained using a questionnaire.

Results: The mean total score in the study group was 17 points out of 21 possible. In the tests, asymmetric differences between the right and left side of the body were observed for 12 players. During the final season, 12 people suffered injuries, among them, 10 of the players reached a score of 17 points or below (83%) in the FMS test.

Conclusions: The use of the Functional Movement Screen Test in young floorball athletes, can detect asymmetry and dysfunction associated with the specifics of practicing this sport. The obtained FMS test result correlates with the history of injuries and contusions. The FMS test is an inexpensive and quick tool for functional assessment and seems to be a useful test for early detection of abnormalities in the patterns and asymmetry of floorball players. In turn, it can prevent and reduce the risk of injury, which is particularly important in young players - juniors.

Introduction

Floorball is a relatively young team game, the popularity of which is growing around the world. In the 30 years of its existence, it has been transformed from a recreational activity to an organized sport. Currently, the International Floorball Federation has 57 members [1]. It includes the Polish Floorball Association, however in our country, this discipline is not still very popular. In the current season (2015/2016) in the men’s extra-league competition, 7 teams are participating, while the women’s extra-league consists of 8 teams. Additionally, the 1st men’s league consists of 6 teams, and in the 2nd league - 32. In the junior category, there are 9 boys’ clubs and the junior girls - 8 teams [2].
Floorball is a discipline that requires players to connect both technical and tactical skills as well as motor skills, such as speed, agility, balance and coordination [3]. Sudden acceleration, stopping and changing direction take place during the game. Often, uncontrolled contact with another player, a collision with a band or hitting with a stick or a ball occur [4].

The most common injuries among floorball athletes are: sprains and dislocations of joints, strains or torn muscles and ligaments. Most of them, because about 70-85% are acute injuries, while a smaller portion are injuries resulting from overload [5]. Due to the nature of the game, they are typical damage within the knee and ankle joints. Usually, these are non-contact injuries, but associated with loss of postural control during sudden halting or changing direction. According to Pasanen [6], among the players’ floorball injuries, the most common are in the knee joints (27%), ankles (22%) and thighs (12%).

In the analyzed literature, however, there is the lack of information about the causes of injuries among athletes training floorball. Considering the fact that it is an asymmetrical discipline, it is puzzling whether the existence of asymmetry irregularities in movement patterns in floorball players is associated with the occurrence of these injuries. For this purpose, the authors have attempted to verify the disorders in the fundamental movement patterns in young floorball players and determine the relationship between the observed dysfunctions, and the occurrence of injuries.

For the evaluation of injury risk assay, the Functional Movement Screen Test (FMS) was used, which consists of 7 functional motor tasks, used to assess the risk of injury, and enable the individual limits of detection, asymmetry or dysfunction. Each task is rated on a scale of 0 to 3 points. The maximum score attainable is 21 points [7]. Research confirms that obtaining a result below 14 points increases the risk of injury from 15 to 51% [8].

However, the occurrence of asymmetric patterns during the FMS test is a stronger risk factor for injury than the low - less than 14 points - result of the test. A player, who received a higher FMS score, but also has a clear disparity between the right and left side of the body is more prone to injury than a person with a lower FMS score and lack of asymmetry in the patterns [9].

Despite the growing popularity of floorball, specialist literature lacks scientific reports on the specifics of injuries occurring among players of this discipline. There are also no studies verifying the relationship between the risk of injury and specific basic motor disorders.

**Aim**

The aim of the study was to assess disorders in the fundamental movement patterns in young floorball players as well as the relationship between the observed disorders and the occurrence of injury. The following research questions were put forward:

1. Can the use of the Functional Movement Screen Test among young floorball players detect asymmetry and dysfunction associated with the specifics of practicing this sport?
2. How frequently do asymmetric movement patterns occur among competitors practicing floorball and are they related to the frequency and location of the occurrence of injuries?
3. Does the FMS test correlates with the history of trauma and injuries of the competitors practicing floorball?

**Material and methods**

1. **Description of the study group**

   The study involved 23 male high-performance floorball players. The age of subjects ranged from 16 to 19 years (mean 18 years +/- 0.8). The athletes training experience averaged 8 years. They were representatives of 9 clubs and training sessions were conducted approx. 3 times a week.

   Prior to testing, each player was informed about the purpose and course of the study and agreed to participation.

2. **Research Method**

   2.1. **Interview**

   The research tool was a questionnaire containing questions about health, training intensity, previous injuries and overburdens during the previous season and undergone treatments. The questionnaire contained 40 questions, most of which were semi-open questions concerning the suffered injuries and the applied treatment. Questions regarding injuries complemented our results of the FMS test.

   2.2. **The Functional Movement Screen Test (FMS)**

   The Functional Movement Screen Test is a comprehensive test for determining the quality of basic movement patterns, requiring the combination of stability, mobility, strength and coordination of the involved muscle groups and proper neuromuscular control.

   The test consists of 7 elements:
   1) deep squat,
   2) hurdle step,
   3) in-line lunge,
   4) shoulder mobility,
   5) ASLR - active straight leg raise,
   6) trunk stability push-up,
   7) rotational stability.
Each of the above samples were evaluated on a 4-level scale of 0 to 3. During testing, the subject was observed from the front, back, and side (in the frontal and sagittal planes). The players did all the tasks wearing shoes. General evaluation criteria were as follows:

3 points were awarded for the correct execution of the locomotor pattern with no apparent compensation, 2 points to perform the motion compensation element, while 1 point meant inability to complete the pattern. If during the performed test pain was felt, 0 points were given. In asymmetric tests, in the case of a difference in results between the left and right side of the body, the final evaluation took the lower result into account. Each test was performed 3 times. The maximum possible score was 21 points. The end result allowed for qualification of the subject into 1 of 3 groups. The section from 18 to 21 points meant that the body moved in the correct movement patterns and the risk of injury is low. In subjects who received 14 to 18 points, compensation and asymmetries occurred and the probability of injury is increased. Obtaining a result below 14 points increases the risk of injury to more than 50%. In addition to the 7 movement patterns, provocation-exclusion tests were also performed:

1) for the test assessing the mobility of the shoulder girdle - provocation test consisting of repeatedly touching one’s forehead with the elbow, with hand stabled on the opposite shoulder;

2) for the trunk stability push-up - provocation test carried out in a face-down lying position, which consists in performing hyperextension of the lumbar spine;

3) test for evaluating the stability of body rotation – provocation test of thoracic spine extension, consisting in transition from a supported kneeling position to sitting on one’s heels without changing hand position on the ground.

In the case of pain during the provocation test, the subject received 0 points for the corresponding motor tasks of the FMS test [9,10]. The test was carried out after completion of the season. Functional assessment of movement patterns used the original protocol and FMS test kit, consisting of a 5cm x 15cm x 150cm base, 2 bars, a disc and rubber. The analysis considered the final result of the test and the results of individual motor tasks.

The reliability of the Functional Movement Screen Test was assessed, among others, by Smithi et al. [11]. This test exhibits the reliability of measurements between the subjects (ICC Inter-rater = 0.87-0.89) and by the same examiner taking them (ICC Intra-rater = 0.81-0.91).

3. Statistical analysis

Statistical analysis was performed using STATISTICA 10.0 Pl. To assess the relationship between the test results of the FMS in individual players, and the occurrence of injury during the previous season, Spearman’s rank correlation was used. It was considered statistically significant if the probability level of the test was lower than the assumed level of significance (p<0.05).

Results

In the study using the FMS test, most players reached a score of 17 points. The lowest recorded value was 14 points, and the highest - 20 points (Fig. 1).

Among the players who suffered injuries during the previous season, most often the result obtained in the FMS test was 17 points, whereas in subjects without

![Fig. 1. The results obtained by floorball players in the FMS test](image-url)
Tab. 1. The mean, standard deviation and modal of results in the FMS test in injured and non-injured floorball players

<table>
<thead>
<tr>
<th>Competitors</th>
<th>No.</th>
<th>Mean</th>
<th>SD</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>23</td>
<td>17.48</td>
<td>1.56</td>
<td>17</td>
</tr>
<tr>
<td>Injury</td>
<td>12</td>
<td>16.58</td>
<td>1.32</td>
<td>17</td>
</tr>
<tr>
<td>No injury</td>
<td>11</td>
<td>18.45</td>
<td>1.15</td>
<td>19</td>
</tr>
</tbody>
</table>

1. Deep squat
2. Hurdle step – OH
2. Hurdle step – OH
3. In-line lunge - RL in front
3. In-line lunge - LL in front
4. Shoulder mobility - RA lifted higher
4. Shoulder mobility - LA lifted higher
5. Active straight leg raise – RL
5. Active straight leg raise – LL
6. Trunk stability push-up
7. Rotational stability - RA lifted higher
7. Rotational stability – LA lifted higher
Total score

Fig. 2. The FMS test results in injured floorball players; tests with compensations are indicated in gray

Fig. 3. The location of injuries
trauma - 19 points. The mean values, standard deviations and the modals, with division into injured and non-injured players, are summarized in the Table 1.

Injuries during the previous season occurred in 12 people. Among them, 10 of the subjects (83%) reached a score 17 points or less in the FMS test (Fig. 2).

Injuries were mostly located within the ankle - 50%, and knee - 33%. Subsequently, they were the femur and calcaneus (17%), and wrist and back (8%) (Fig. 3).

In asymmetric assays, the differences between the right and left side of the body were seen in 12 players, 6 of them (50%) experienced trauma in the past season. Generally, differences occurred in the test: hurdle step and ASLR (in 4 players). For 3 of the participants, evaluation of the rotational stability test revealed asymmetry. In turn, in-line lunge and shoulder mobility showed the least differences between the sides (Fig. 4).

The Spearman correlation coefficient between the FMS test result and the occurrence of the injury was $R = 0.65$ ($p <0.001$).

**Discussion**

Floorball is a very young sports discipline, popular especially among children and adolescents. However, its disadvantage is the asymmetry, because usually one side of the body is dominant, and systematic training worsens the occurrence of abnormal patterns, which is particularly dangerous for young athletes training floorball.

Functional assessment using the Functional Movement Screen test is widely used in modern sports and medicine. This system is considered by many authors as a valuable screening test, because it allows comprehensive assessment of motor patterns and the risk of injuries and contusions [12-14].

Our results showed that the use of the test FMS among young floorball players can help detect asymmetry and dysfunction associated with the specifics of practicing this sport. Furthermore, carrying out interviews with the subjects concerning training, health, injuries and overburdening during the previous season helped to determine the relationship between the results obtained in the FMS test, and the incidence of injuries.

In this paper, for the first time the FMS test was used to assess the floorball players. It has been shown that the offsets observed in athletes, associated with a low score in the FMS test may increase the risk of injury. The results show a strong positive correlation between the results the FMS test and the occurrence of injury during the last season. A similar correlation was also observed between the frequency of injuries occurring and asymmetry.

In literature, there are no reports on disturbances of fundamental movement patterns in young floorball players, as well as the existence of the relationship between the observed disorders and the occurrence of injury. However, a number of studies have been conducted that have utilized the test to evaluate the players of other sports disciplines [15-17].
The Functional Movement Screen test is a comprehensive, simple and easily accessible research tool, used to assess the quality of functional movement patterns. Its creator is Gray Cook - American physiotherapist and specialist in the field of functional training and motor preparation. The purpose of the test is to detect individual limits, asymmetry or dysfunction that can lead to injury. This allows for the introduction of an appropriate corrective procedure, aiming to reduce the risk of injury and improve the quality of movement patterns [7].

The Functional Movement Screen test has been used mainly among athletes. Kiesel et al. [17] conducted a study, the aim of which was to determine whether the use of a special training program carried out during the players’ off-season could improve the results of the FMS. Exercises were selected individually for each football player, based on the results obtained during the first test. Their goal was elimination of the identified dysfunctions, limitations or asymmetries. The results obtained after a 7-week exercise program indicated the positive effect of the applied training on the final value of the FMS test during re-examination. The number of players that were given a number of points greater than 14 increased, while the percentage of players in which asymmetry could be observed decreased.

Another work by Kiesiel et al. [8] described the relationship between the result obtained in the Functional Movement Screen test and the incidence of injury in football players. The study was conducted before the beginning of the season. It was observed that persons who had obtained fewer points during the season in the test, were often afflicted with trauma. The average score of the injured athletes was 14.3 points. While the players who did not suffer injury, the FMS test result averaged 17.4 points. We found that in the case of obtaining 14 points or less, the risk increases from 15% to 51%.

In our study, the players achieved slightly higher results in the FMS test. Among those injured, the average was about 16.6 points. While the players who did not suffer injury were evaluated at an average of 18.5 points. These differences may be due to the specific nature of the sport. Floorball and football involves usage of different muscles and body segments, which leads to the occurrence of different asymmetry or overload in the musculoskeletal system.

The Functional Movement Screen test is also used among athletes of other disciplines. Chorba et al. [12] evaluated a group of 38 female basketball, volleyball and football players. The average test score was 14.3 points. It was found that the acquisition of 14 points or less was strongly correlated with the occurrence of injury. Among the women who achieved such a result, 69% had experienced injuries in the past. The researchers concluded that the occurrence of compensatory movement patterns may increase the risk of injury among women playing basketball, volleyball or football. Also they found that using the FMS test is possible to detect malfunctions, which can prevent injuries.

Similar results were obtained by Lisman et al. [13], who used the Functional Movement Screen test for risk assessment and prevention of injuries among soldiers, who were members of the Marine Corps. They also conducted fitness tests, in which one of the elements was a 3-mile run. The researchers found that getting 14 points or less in the FMS test, combined with a weak result in the running test (7 minutes per mile or slower) was associated with a higher risk of injury among soldiers.

In a following study, Klusmann et al. [16] described the correlation between the results obtained in the Functional Movement Screen test and performance test. The study included 39 basketball players of both sexes between the ages of 14 and 17. The authors observed a moderate correlation between the results of FMS, and the results of fitness tests, evaluating strength, agility and flexibility. It was found that the dysfunctions and limitations in the basic movement patterns studied by FMS may reveal areas for which appropriate training must be applied. The test result can be a valuable clue for trainers.

Minick et al. [18] conducted a study the purpose of which was to assess reliability of the Functional Movement Screen test evaluated by different raters. This showed compatibility of assessment and high repeatability of the test results of the FMS test among the different subjects. The weighted Kappa (Kw) was calculated comparing the average results of the test evaluation, which was conducted by novice researchers and a group of experts. It was observed that 14 out of 17 tests demonstrate excellent evaluation compatibility, particularly in the rotational stability test (KW = 0.74). The results confirmed the practical value and the possibility to use this test in testing athletes.

In this study, the location of the injuries occurring among the tested floorball players was determined. Most were related to the ankle- (50%) and knee-joints (33%). Further injuries were to the thigh and the calcaneus (17%), and wrist and back (8%).

In literature, a few studies considering a similar subject can be found. Snellman et al. [19] evaluated the frequency and location of injuries occurring among licensed floorball players in Finland (199 men and 96 women). During the season, 34% of the subjects suffered injuries (37% of men and 28% of women). Acute injuries accounted for 83%, while 17% of the occurring injuries resulted from overload. The most common injury locations were the knee- (22%) and ankle-joints (20%).
Similar results were also obtained by Pasanen et al. [20], who analyzed the number of injuries in a group of 374 women who were first and second division floorball athletes in Finland. 35% of them suffered injuries during the ongoing season, of which 70% were sudden events, and 30% resulted from overload. The most common injuries involved the knee- (27%) and ankle-joints (22%).

In turn, Wikstrom and Andersson [21] evaluated 457 Swedish floorball players, studying the occurrence of injuries. During the season, 11% of them experienced trauma. Of all the injuries, 36% were defined as light (causing exclusion from training for 7 days), 29% as moderate (exemption from training for a period of 8 to 30 days), while 35% of injuries were the reason for absence lasting more than 30 days. The most frequently injury reported by the subjects was a twisted ankle.

Based on a review of the available literature, it can be stated that the Functional Movement Screen system can be a practical tool to assess disorders of the fundamental movement patterns in young floorball players. Furthermore, the studies carried out by different authors suggest a relationship between the observed disorders and the occurrence of injuries. Using the FMS test in this study, asymmetries and dysfunctions associated with the specifics of practicing this sport were detected for about half of the people practicing floorball. 50% of subjects for whom we observed differences between the right and left side of the body, suffered injury recently. Injuries most often concerned the ankle- and knee-joints.

This study is the first in which movement patterns were assessed using the test FMS and the results were correlated with the occurrence of injuries in athletes of this sport (R = 0.65).

The limitation of this study could be the small number of the study group. It was connected with the selection of the group, since we only considered high-class players. We recommend further research to clearly confirm the relationship between the results achieved in the FMS test and the number of injuries among floorball athletes.

Given the growing popularity of floorball, as well as the proneness to injury while performing this discipline, much attention should be paid to prevention of injuries. The Functional Movement Screen test may be a useful tool allowing for indentification of multifaceted asymmetry disorders in movement between segments of the body, which can lead to injury. Therefore, it allows for the introduction of appropriate functional training, aiming to reduce the risk of injury and improve the quality of movement patterns.

Conclusions

1. Floorball, due to its characteristics, contributes to asymmetry among competitors practicing this sport.
2. Usage of the Functional Movement Screen test among young floorball players can help detect asymmetry and dysfunction associated with the specifics of practicing this discipline.
3. The FMS test correlates with the history of trauma and injuries of competitors practicing floorball.
4. The FMS test is an inexpensive and quick tool for functional assessment and seems to be a useful research instrument for early detection of abnormalities and asymmetries in the patterns of floorball players.
5. The frequency of asymmetric patterns occurrence among competitors practicing floorball is related to the frequency and location of the occurrence of injuries.

References


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THE INFLUENCE OF AN ADDITIONAL LOAD ON RAMBLING-TREMBLING COP SIGNAL DECOMPOSITION

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Keywords: posturography, postural control, body balance, external load

Abstract

Purpose: The aim of this study was to determine the contribution of additional body load on COP components using rambling and trembling signal decomposition.

Basic procedures: Thirty healthy, untrained physical education students were examined. Static balance was assessed using a force platform with a sampling frequency of 100 Hz, which registered ground reaction forces and moments. The research project consisted of quiet standing (QS) trials performed in three different conditions: without extra load, with 7 kg and 10 kg extra load. All trials lasted 30 seconds and were repeated three times. The raw data were processed using MatLab. The following variables were analyzed: velocity COP (vCOP), range COP (raCOP), root mean square COP (rmsCOP). In addition, COP signals were decomposed on rambling and trembling components. Two-way analysis of variance with repeated-measures was performed to compare the results of different quiet standing conditions. The Bonferroni post-hoc test was applied to determine significant differences (level of significance: p< 0.05).

Main findings: Significantly higher values of vCOP and v-tremb were observed between the first and third QS trials (p<0.05). Also, significantly higher values of ra-tremb and rms-tremb were registered between the first and second QS trials (p <0.05). Whereas significantly lower values of ra-ramb were observed between the first and third QS trials, as well between the second and third QS trials (p< 0.05).

Conclusion: External body load increased the inertial force increasing range of COP sway, as evidenced by visible trembling components in each of the analyzed variables of quiet standing. Changes of different character were observed in rambling components. Extra load decreased the differences between extreme deviation of COP along the sagittal axes.

Introduction

Maintaining an upright position covers a wide range of issues related to postural control, spatial orientation and the effects of various forces on the human body. Along with the change in size and geometry of the body, affecting overweight and obese people, is a change in postural stability [1]. With the increase in the mass of individual body segments, changes occur in the location of the overall center of gravity (COG), which moves closer to the front boundary of the support area. This also probably influences the increase in torque generated in the ankle, needed to maintain upright posture [2]. It is known that obesity increases the average speed of COP as well as the linear range of postural sway [3]. Therefore, in this study, we have also decided to artificially intervene in body mass and shape, requiring the subject to wear a load-vest. It was discussed whether it would be pos-
sible in laboratory conditions to obtain similar changes in the parameters of quiet standing, which are presented by obese people.

In posturographic studies, force platforms are widely used, recording ground reaction forces of the center of foot pressure – (COP). On the basis of the COP signal, analyzes are carried out to assess postural stability. Many researchers find the informative value of standard variables describing the COP insufficient [4, 5, 6]. Therefore, in order to better understand the mechanisms of postural sway, it is recommended to use methods of COP signal decomposition. In these studies, the rambling-trembling method proposed by Zatsiorski and Duarte is used [5]. The method assumes that through the CNS sets a reference point, against which balance is maintained. This point is not static and constantly changes its position. Any deviation from its trajectory triggers mechanisms to restore balance. The trajectory formed by the migrant reference point is determined with rambling. Other movements resulting from force activity which aim to restore balance within the system are called trembling. The postural control system can also be understood as a two-level hierarchical system consisting of supra spinal (rambling) and spinal (trembling) control. Therefore, in this study, it was decided to examine whether placing an additional load on the human body would affect the signal components. It was also assumed that an external load would increase the corrective component (trembling) of the COP signal.

**Methods:**

The study involved 30 healthy, untrained physical education students. Their average age, body mass and body height was as follows: 21 ± 2.5 years, 70 ± 10 kg and 172 ± 10 cm. After a preliminary analysis of the data, it was found that the sex of the subjects did not have significant impact on the obtained results. Due to this fact, the analyzes did not take into account the factor of gender, and comparison between different conditions was carried out within a study group composed of 17 men and 13 women. The subjects gave informed written consent for voluntary participation in the experiment. Students participating in the experiment reported no problems with balance and did not declare undergoing any surgery or musculoskeletal injuries. No subjects reported any neurological disorders. The study was approved by the Bioethics Committee of the Jerzy Kukuczka AWF in Katowice.

The test procedure involved trials of quiet standing (feet set apart analogous to hip-width, arms at one’s sides, facing forwards) in three measurement conditions (Fig. 1). The first attempt always took place with no additional burden, the following two with an appropriate burden in the form of a load-vest, randomly selected. Each trial in the given measurement condition lasted 30 seconds, and was repeated three times [7].

The study applied an extra load using the load-vest (Body Sculpture BB 691), with an adjustable load (250 gram weights). The maximum vest-load was 10 kilos. The study was conducted using the AMTI (Accugait, USA) force plate with the AMTI NetForce Software. The platform registered the ground reaction forces and moments, which were further processed using MatLab software. The platform sampling frequency was set at 100 Hz. The platform data were further processed with 7 Hz, fourth-order, low-pass Butterworth filter. The rambling and trembling COP signal components were calculated on the basis of the instructions described by Zatsiorskoy and Duarte [5, 6].

This method decompose the trajectory COP signal down to rambling (central) and trembling (muscular) components. Appointment of the rambling trajectory is based on the location of all the moments in time at which the horizontal forces are equal or close to zero and are referred to as points of momentary balance. These points are interpolated with cubic splines method, creating a new reconstructed rambling trajectory. Subtracting the rambling component of the COP trajectory

| Table 1. Characteristic of the analyzed posturography parameters |
|---|---|---|---|
| Abbreviation | Meaning | Unit | Definition |
| vCOP | v- velocity | [cm/s] | Quotient of COP path length to duration of the measurement |
| v-ramb | ra-COP | [cm] | Extreme deviation of COP along appropriate axes. |
| ra-ramb | rms-COP | [cm] | General displacement of COP within support surface |
| ra-tremb | rms-ramb | | |
| rms-tremb | | | |

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signal results in the creation of a new signal, namely the trembling trajectory. It is linked with COP departing from the point of balance position. Conducting the above analysis allowed to isolate the COP variables, which are presented in Table 1. These parameters of quiet standing were analyzed in the anterior-posterior plane.

The basic parameters of descriptive statistics were calculated. Two-way analysis of variance with repeated measures and the analysis of the post-hoc Bonferroni test were conducted to assess the significance of differences between the recorded variables. The result was considered significant at \( p \leq 0.005 \). All calculations were carried out using STATISTICA 10.

**Results**

The variables were individually calculated for each measurement condition (quiet standing, quiet standing - 7 kg, quiet standing - 10 kg). Sequentially, variables of the classic COP signal and rambling and trembling components were analyzed. Analysis of variance showed a significant correlation of variables \( \text{vCOP}, \text{ra-ramb}, \text{rms-temb}, \text{ra-tremb}, \text{v-tremb} \) of the additional load (Tab. 2, 3 and 4).

After application of the external load, significantly higher average values of COP velocity and the velocity of trembling components were observed between the 1\(^{\text{st}}\) and 3\(^{\text{rd}}\) quiet standing trials (Figs. 2 and 6). Significantly higher average values of the range and root mean square of the average COP trembling component position were noted between the 1\(^{\text{st}}\) and 2\(^{\text{nd}}\) quiet standing trials (Figs. 4 and 5). On the other hand, the opposite situation was observed with the average value change of the range of rambling components, where the additional load significantly reduced the average values of this parameter. Significant differences were observed between the 1\(^{\text{st}}\) and 3\(^{\text{rd}}\), and the 2\(^{\text{nd}}\) and 3\(^{\text{rd}}\) quiet standing trials (Fig. 3).

**Table 2. Analysis of variance for COP signal variables**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average</th>
<th>SD</th>
<th>SS</th>
<th>MS</th>
<th>SS error</th>
<th>MS error</th>
<th>F (2, 58)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>raCOP (I)</td>
<td>1.881</td>
<td>0.517</td>
<td>0.516</td>
<td>0.026</td>
<td>4.849</td>
<td>0.084</td>
<td>3.086</td>
<td>0.053</td>
</tr>
<tr>
<td>raCOP (II)</td>
<td>1.926</td>
<td>0.511</td>
<td>0.447</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>raCOP (III)</td>
<td>1.748</td>
<td>0.447</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rmsCOP (I)</td>
<td>0.389</td>
<td>0.120</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>rmsCOP (II)</td>
<td>0.387</td>
<td>0.121</td>
<td>0.014</td>
<td>0.007</td>
<td>0.242</td>
<td>0.004</td>
<td>1.733</td>
<td>0.185</td>
</tr>
<tr>
<td>rmsCOP (III)</td>
<td>0.655</td>
<td>0.112</td>
<td>0.052</td>
<td>0.026</td>
<td>0.346</td>
<td>0.006</td>
<td>4.345</td>
<td>0.017</td>
</tr>
<tr>
<td>vCOP (I)</td>
<td>0.596</td>
<td>0.112</td>
<td>0.052</td>
<td>0.026</td>
<td>0.346</td>
<td>0.006</td>
<td>4.345</td>
<td>0.017</td>
</tr>
<tr>
<td>vCOP (II)</td>
<td>0.619</td>
<td>0.127</td>
<td>0.360</td>
<td>0.055</td>
<td>3.214</td>
<td>0.004</td>
<td>6.494</td>
<td>0.003</td>
</tr>
<tr>
<td>vCOP (III)</td>
<td>0.655</td>
<td>0.154</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

(I): first quiet standing trial, (II): second quiet standing trial – 7 kg, (III): third quiet standing trial – 10 kg

**Table 3. Analysis of variance for variables of COP signal rambling component**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average</th>
<th>SD</th>
<th>SS</th>
<th>MS</th>
<th>SS error</th>
<th>MS error</th>
<th>F (2, 58)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>ra-ramb (I)</td>
<td>1.746</td>
<td>0.451</td>
<td>0.720</td>
<td>0.360</td>
<td>3.214</td>
<td>0.055</td>
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<td>0.003</td>
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<td>ra-ramb (II)</td>
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<td>0.482</td>
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<tr>
<td>ra-ramb (III)</td>
<td>1.572</td>
<td>0.398</td>
<td>0.019</td>
<td>0.009</td>
<td>0.222</td>
<td>0.003</td>
<td>2.568</td>
<td>0.085</td>
</tr>
<tr>
<td>rms-ramb (I)</td>
<td>0.372</td>
<td>0.114</td>
<td>0.114</td>
<td>0.114</td>
<td>0.019</td>
<td>0.009</td>
<td>0.222</td>
<td>0.003</td>
</tr>
<tr>
<td>rms-ramb (II)</td>
<td>0.365</td>
<td>0.097</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rms-ramb (III)</td>
<td>1.572</td>
<td>0.107</td>
<td>0.013</td>
<td>0.006</td>
<td>0.181</td>
<td>0.003</td>
<td>2.169</td>
<td>0.124</td>
</tr>
<tr>
<td>v-ramb (I)</td>
<td>0.505</td>
<td>0.113</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v-ramb (II)</td>
<td>0.519</td>
<td>0.113</td>
<td>0.013</td>
<td>0.006</td>
<td>0.181</td>
<td>0.003</td>
<td>2.169</td>
<td>0.124</td>
</tr>
<tr>
<td>v-ramb (III)</td>
<td>0.535</td>
<td>0.112</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(I): first quiet standing trial, (II): second quiet standing trial - 7kg, (III): third quiet standing trial – 10kg
Table 4. Analysis of variance for variables of COP signal trembling component

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average</th>
<th>SD</th>
<th>SS</th>
<th>MS</th>
<th>SS error</th>
<th>MS error</th>
<th>F (2, 58)</th>
<th>p</th>
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<td>0.015</td>
<td>0.003</td>
<td>0.016</td>
<td>0.000</td>
<td>0.016</td>
<td>4.904</td>
<td>0.011</td>
</tr>
<tr>
<td>rms-tremb (II)</td>
<td>0.050</td>
<td>0.026</td>
<td>0.198</td>
<td>0.099</td>
<td>1.499</td>
<td>0.198</td>
<td>3.835</td>
<td>0.027</td>
</tr>
<tr>
<td>rms-tremb (III)</td>
<td>0.048</td>
<td>0.019</td>
<td>0.028</td>
<td>0.014</td>
<td>0.125</td>
<td>0.028</td>
<td>6.450</td>
<td>0.003</td>
</tr>
<tr>
<td>ra-tremb (I)</td>
<td>0.444</td>
<td>0.181</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ra-tremb (II)</td>
<td>0.558</td>
<td>0.246</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ra-tremb (III)</td>
<td>0.514</td>
<td>0.191</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>v-tremb (I)</td>
<td>0.223</td>
<td>0.092</td>
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<td>v-tremb (II)</td>
<td>0.239</td>
<td>0.077</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>v-tremb (III)</td>
<td>0.265</td>
<td>0.096</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(I): first quiet standing trial, (II): second quiet standing trial - 7kg, (III): third quiet standing trial - 10kg

Figure 1. Experimental set-up

Figure 2. Analysis of velocity of COP in the sagittal plane in quiet standing trials.
The influence of an additional load on rambling-trembling cop signal decomposition

Figure 3. Analysis of range of rambling component of COP signals in the sagittal plane in quiet standing trials.

Figure 4. Analysis of root mean square of trembling component of COP signal in the sagittal plane in quiet standing trials.

Figure 5. Analysis of range of trembling component of COP signal in the sagittal plane in quiet standing trials.
Discussion

The aim of the experiment was to investigate the effects of the additional load placed on the trunk of the subject on COP signal rambling and trembling components. Research also allowed to determine the nature of the changes that occurred in the parameters of quiet standing after applying the external load. It also allowed to answer the question of whether the load-vest can cause the same changes in the COP signal as can be observed in obese people.

The imposition of the load-vest weighing 10 kg on the subject resulted in higher COP velocity and trembling component values by an average of 10%, compared to the no-load measurements. In turn, the 7-kg load caused a change in the values of the root mean square of the average trembling components. The registered values for this parameter were higher by an average of 35% compared to the no-load measurements. The direction of these changes coincides with reports in the references. Qu et al. [8] also reported higher COP velocity and the square root of the average COP. These changes oscillated around 8% for the variable velocity and around 10.4% for the square root variable of the average COP position. Paunaxallio et al. [9] also recorded higher COP velocity values by 10.4% in the group of young people, and almost 40% in the elderly group. In turn, Schifffman et al. [10] and Heller et al. [11] analyzed changes occurring in the COP velocity derivative, namely, the path length of COP. The additional load lengthened the distance overcome by COP during quiet standing. Changes occurring in COP velocity parameters and the root mean square of the average COP position when an additional load is placed on the subject reflect changes that are represented by obese persons [12, 13].

External load increases postural sway, as evidenced by the resulting higher velocity and the root mean square of the average COP position. Increasing postural sway during quiet standing leads to the general center of gravity (COG) getting close to the boundary of the base of support [14]. These changes may lead to decreased postural stability. Additional loads can delay the flow of feedback on the state of equilibrium of the body. This affects postural control mechanisms that allow one to maintain an upright position. To prevent loss of balance, any deviations from equilibrium are immediately corrected and permit returning to the correct state. These corrections, after placing the external load on the subject, are reflected in an increased postural sway [9]. Vertical posture is often compared in literature to the model of inverted pendulum [15, 16]. Application of an external load can make the system less stable. Load-vests increase the subjects’ force of inertia, causing deviations from the vertical position of the body [11].

The trembling component of COP signal decomposition is associated with the muscular component. Thus, for the higher velocities, the extent and position of the root mean square of the average COP position is associated with an increased response from the musculoskeletal system. This is confirmed in the study by Schiffman et al. [10], in which the equipment was used to record EMG activity of the muscles involved in maintaining body balance. After applying the additional load, increased activity of the bioelectric extensor back muscle and rectus femoris muscles could be observed. The load-vest changes patterns of muscle activity required to maintain an upright position [11].

Figure 6. Analysis of velocity of COP signal trembling component in the sagittal plane in quiet standing trials.
The influence of an additional load on rambling-trembling cop signal decomposition

The changes registered in the values of the rambling component range adopted a different nature, compared to the changes that occurred in the other analyzed variables. After placing the external load on the subject, lower values of this parameter by an average of 11% were reported, compared to the measurement without the load. This result is surprising compared to the research of other authors who have achieved higher COP ranges [10, 11, 17]. In this case, the additional load reduced extreme deviation of COP from the sagittal axis. This result is also different from what we have observed in obese people.

Many studies have been conducted that are associated with the use of additional loads in terms of postural control, postural stability and functional balance. However, the manners of application and the sizes of the additional loads in these works are varied. Depending on the purpose of the experiment, the additional load was placed on the front of the chest, [17] the back of the chest [18, 21], and also equally on the front and back of the trunk [9, 10]. A similar situation can be seen in terms of selecting the external load size. Some of the researchers apply the additional load relative to the subject’s percentage of body mass. It oscillates between 10%, 15% and 20% of body mass [8, 19]. Also, such works can be found in which constant external loads were applied, not considering the body mass of the subject [10, 20]. Despite these differences, the authors obtained similar results in their studies, suggesting that the external load decreases postural stability.

Future studies should take account of the location of the external load on the subject’s body. One of the reasons may be the fact that there are several types of obesity, including basic, android, gynoid [22]. Repositioning the additional load would allow to more precisely map the specific type of obesity. In this case, also more legitimate would be a percentage selection of additional loads, relative to the body mass of the subject. Especially if the research group is numerous and diverse in terms of gender. In addition, the studies should implement bioelectrical potential of postural muscle measurement [EMG]. With the change of position of the additional load, such changes occurring in muscle activity involved in maintaining posture could be observed. The inclusion of EMG testing can simultaneously contribute to a better understanding of the mechanisms of postural control in obese persons.

Conclusions

1) Placing the external load on the body of the subject resulted in noticeable changes in values of quiet standing parameters (Tab. 1). Both 7-kg and 10-kg loads influence the stability of the subjects’ posture.
2) Exterior loads increase inertia of the subject’s body, increasing the range of postural sway, as evidenced by the visualized trembling component in each analyzed variable in the studied group.
3) It cannot be unequivocally stated that artificially imposing a load-vest causes the same changes in the parameters of quiet standing that can be observed in obese persons.

References


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THE TYPE OF BENCH PRESS BASED ON THE CRITICAL FEATURES THE TYPE OF BENCH PRESS

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Key words: biomechanics, pantograph, bench press, kinematics and kinetics parameters

Abstract

The aim of this study was to determine the type of flat bench press based on the critical features of the bench press. Twenty healthy men took part in the study. Temporal positions of the barbell were registered using a special device called a pantograph. This device identified the descent and ascent phases (lift), and calculated the mechanical parameters (velocity, mechanical power). It turned out that while trying to lift the bar as quickly as possible, a high average power is developed. To measure the degree of dependence, the Pearson correlation coefficient between the average values of the mechanical power during the ascent phase and the lift duration were calculated. Then, cluster analysis was conducted to determine the certain groups that each individual subject belonged. Cluster analysis was then carried out and showed that all the subjects can be split into two groups. Group 1 was the group which lifted the barbell at a slower tempo and did so at small values of the average power (the cluster contained 11 cases). Group 2 was the group which quickly lifted the barbell and did so at high values of the average power (the cluster included 9 cases).

1. Introduction

A barbell bench press can be done in several ways, depending on the desired goal. Most people who do exercises prefer a slow, controlled lowering and then lifting of the barbell. Others leave the bar slowly but they try to lift it a bit faster. Yet, another group of athletes tries to use muscle actions in the stretch-shortening cycle (SSC), i.e., after finishing a quick lowering of the barbell, with one swift movement, they raise it up quickly and smoothly without stopping.

The vast majority of different sports techniques make use of the stretch-shortening cycle. This cycle includes the time needed to switch from the eccentric loading phase of the movement to the concentric power production phase. During the eccentric contraction, the muscle extends while being tense because the opposing force is greater than the generated one. The concentric contraction occurs when the muscle shortens during tension. This muscle shortening happens because the force generated by the muscle is greater than the force opposing it. The rapid eccentric phase of the muscle contraction stimulates the

1 It seems obvious that the use of muscle actions in the stretch-shortening cycle during the bench press is a difficult task because this phenomenon revolves around vigorous movements requiring a lot of effort. Jumping is an example of such muscle actions in the stretch-shortening cycle.
muscle spindle and the elastic properties of the muscle. Powerful and immediate concentric contraction is, thus, facilitated. This contraction gives the possibility of using both the elastic energy of the muscle, which emerges during the rapid lowering phase (eccentric contraction), and a stretch (myotatic) reflex appearing in a later concentric contraction [1]. From the point of view of the correctness of the movement, the period of time in which the barbell is kept on the chest during the flat bench press using the SSC should be as short as possible. The effect of the movement is increased in the form of a greater initial force [2]; the principle of the initial force [3].

The form of motion using the SSC should be recommended if the purpose of an athlete is to obtain the best results in the bench press. This form of motion with the SSC can be used both by athletes who practice the sport recreationally, and by weightlifters. Due to the current regulations existing in the International Powerlifting Federation stating that a barbell must be stopped on the chest, the SSC form of the motion cannot possibly be used by powerlifters.

A similar geometry of the bench press performed, for example, by a bodybuilder and a powerlifter does not mean the same exercise. The differences relate to the rhythm\(^2\) and cadence\(^3\) of movements. Some features (factors) to be taken into consideration are: the size of the load, the number of repetitions in a series of exercises, and above all, the purpose of the exercise.

Considering the aforementioned statements, the basic evaluation criteria (the critical features [5,6]) in the evaluation process of the flat bench press can be either the velocity given to the barbell during the ascent phase or the mechanical power that is developed, and the rhythm of this movement.

The aim of this study was to determine the type of flat bench press based on the critical features of bench press.

### 2. Material and Methods

#### 2.1. Subjects

Twenty healthy men took part in the study (Table 1). The participants were informed about the nature of this study. Prior to data collection, the men were required to sign a consent form in accordance with the regulations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Subject</th>
<th>Body mass (kg)</th>
<th>Body height [cm]</th>
<th>Age [years]</th>
<th>Training experience [years]</th>
<th>Barbell mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^a)</td>
<td>T.T.</td>
<td>74</td>
<td>177</td>
<td>24</td>
<td>1.5</td>
<td>70, 77.5, 85, 92.5</td>
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<tr>
<td>2(^a)</td>
<td>Ł.M.</td>
<td>83</td>
<td>174</td>
<td>22</td>
<td>5</td>
<td>105, 120, 130, 150</td>
</tr>
<tr>
<td>3(^a)</td>
<td>M.P.</td>
<td>95</td>
<td>182</td>
<td>26</td>
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<td>100, 115, 130, 145</td>
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<tr>
<td>4(^a)</td>
<td>A.G.</td>
<td>82</td>
<td>170</td>
<td>24</td>
<td>4</td>
<td>82.5, 95, 107.5, 120</td>
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<td>5(^a)</td>
<td>Ł.J.</td>
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<td>167</td>
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<td>78</td>
<td>173</td>
<td>23</td>
<td>2</td>
<td>62.5, 70, 80, 90</td>
</tr>
<tr>
<td>9(^a)</td>
<td>B.M.</td>
<td>86</td>
<td>182</td>
<td>24</td>
<td>1</td>
<td>70, 80, 90, 95</td>
</tr>
<tr>
<td>10(^a)</td>
<td>J.M.</td>
<td>73</td>
<td>175</td>
<td>24</td>
<td>4</td>
<td>70, 80, 90, 100</td>
</tr>
<tr>
<td>11(^a)</td>
<td>K.K.</td>
<td>82</td>
<td>188</td>
<td>25</td>
<td>4</td>
<td>90, 100, 110, 115</td>
</tr>
<tr>
<td>12(^a)</td>
<td>G.S.</td>
<td>77</td>
<td>171</td>
<td>26</td>
<td>4</td>
<td>95, 110, 125, 135</td>
</tr>
<tr>
<td>13(^a)</td>
<td>P.H.</td>
<td>67</td>
<td>178</td>
<td>26</td>
<td>3</td>
<td>62.5, 70, 77.5, 82</td>
</tr>
<tr>
<td>14(^a)</td>
<td>M.O.</td>
<td>81</td>
<td>185</td>
<td>24</td>
<td>1</td>
<td>80, 90, 100, 105</td>
</tr>
<tr>
<td>15(^a)</td>
<td>J.C.</td>
<td>82</td>
<td>182</td>
<td>22</td>
<td>2</td>
<td>80, 90, 100, 105</td>
</tr>
<tr>
<td>16(^a)</td>
<td>M.S.</td>
<td>80</td>
<td>176</td>
<td>24</td>
<td>3</td>
<td>80, 90, 100, 105</td>
</tr>
<tr>
<td>17(^a)</td>
<td>K.L.</td>
<td>94</td>
<td>192</td>
<td>25</td>
<td>3.5</td>
<td>80, 90, 100, 110</td>
</tr>
<tr>
<td>18(^a)</td>
<td>K.B.</td>
<td>92</td>
<td>195</td>
<td>24</td>
<td>4</td>
<td>60, 70, 80, 90</td>
</tr>
<tr>
<td>19(^a)</td>
<td>T.S.</td>
<td>77</td>
<td>175</td>
<td>25</td>
<td>4</td>
<td>70, 80, 90, 95</td>
</tr>
<tr>
<td>20(^a)</td>
<td>S.S.</td>
<td>90</td>
<td>175</td>
<td>24</td>
<td>7</td>
<td>85, 100, 115, 130</td>
</tr>
</tbody>
</table>

\(^a\) The rhythm of the movement is defined as the duration ratio of the subsequent phases of the exercise (movement) [4].

\(^a\) The cadence (frequency) is the number of repeated movements per time unit [4].
The research project was approved by the Jerzy Kukuczka Academy of Physical Education Bioethics Committee in Katowice, Poland. The subjects performed a flat bench press using free weights and a “touch-and-go” technique. All participants were non-professional weightlifters. They followed powerlifter or bodybuilder styles of training. Prior to the research, all subjects had to have at least one year of weight lifting experience and the ability to do a bench press of at least 100 percent of their body mass.

2.2. Exercise

The research information for the study was collected during the warm-up and the main session. After a general warm-up (a 10 minute run on a treadmill, and stretching), all participants performed a more specific warm-up that consisted of three sets of 10 to 5 repetitions with light weights selected by the subjects (at 40-60% 1RM of the flat bench press). In the main session, the participants performed consecutive sets of a single repetition of flat bench pressing, and each time with an increased load (70, 80, 90, and 100% 1RM the anticipated maximal weight), until the appointment of one maximum repetition. The resting periods between the trials lasted about 5 min and were provided to avoid muscular fatigue.

2.3. Measuring system of the barbell movement

Temporal positions of the barbell were registered using a special device called a pantograph. This device identified the descent (lowering) phase, and ascent (pressing; lift) phase and calculated the mechanical parameters (velocity, mechanical power). The pantograph was used to define the motion of the barbell in the sagittal plane. The motion of the barbell in each and every repetition was divided into two phases: the descent phase and the ascent phase. Considering the data describing the kinematics of the barbell, the following variables were calculated to define the quantitative motion of the barbell i.e. duration of lowering and lifting the barbell, both average and peak power obtained during the lift phase, peak velocity, and duration of gaining peak power. Each phase was specified in terms of its duration. Afterwards, the rhythm of the barbell bench press was specified.

2.4. Statistical analysis

Statistical analysis was carried out using the Statistica v. 9.0 software (Statsoft, USA). Descriptive statistics (average and standard deviation) for all measured mechanical parameters were also calculated. To measure the degree of dependence, the Pearson correlation coefficient between the average values of the mechanical power during the ascent phase and the lift duration was calculated. The level of significance was determined at p<0.05. Then, cluster analysis was conducted to determine the particular groups to which each individual subject belonged. Subjects belonged either to the group which develops high power and performs quick movement, or to the group in which the participants lift the barbell with a slower tempo and low power.

3. Results

The values of the basic kinematic and kinetic parameters of the flat bench press are shown in Tables 2, 3, and 4, and Figures 1, 2, 3, and 4.

The rhythm of the movement defined quantitatively (a ratio of the duration of the descent phase to the duration of the ascent phase) changes as the load increases (Table 2). This action is mainly due to the increase in duration of the ascent phase (Table 4). It can also be stated that together with an increased weight load, not only the duration of the lifting (ascent) phase increases but there is also a decrease in the peak velocity and the average power in the ascent phase (Tables 2 and 4; Figure 1). Such regularity was not detected in the descent phase, mainly due to small differences in the duration of this phase. Only an increase in the negative average power was observed when the load was increased (Table 3).

For this reason, Pearson’s correlation analysis was implemented. This analysis showed significant dependence between the duration of the ascent phase and the magnitude of the mean power developed in this phase. Regardless of the weight to be lifted, a considerable negative correlation between these quantities was observed. On the one hand, the Pearson correlation coefficient \( r \) amounted to 70% 1RM -0.73 (p<0.001), to 80% 1RM -0.71 (p<0.001), and to 90% 1RM -0.72 (p<0.001), and on the other hand, to 100% 1RM -0.83 (p<0.001) for a load of 70 and 100%, respectively.

Cluster analysis was then carried out and showed that all the subjects can be split into two groups (Table 5). Group 1 was the group which lifted the barbell at a slower tempo and did so at small values of the average power (the cluster contains 11 cases). Group 2 was the group which quickly lifted the barbell and did so at high values of the average power (the cluster includes 9 cases).

Furthermore, it is of interest to compare the characteristics of barbell velocity and the mechanical power in the bench press (Figures 1 and 2 – for the subject G.S.; Figures 3 and 4 – for the subject M.S.). In terms of the shape of the curves, the characteristics present a very strong similarity.

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4 The construction and the operating principle of the pantograph was presented in detail by Nawrat [7], and the calculation procedure was shown by Hamar [8].
It is the scientific designation of the point where the initial velocity of the barbell as it blasts off the chest has decreased the most, before it starts to increase again until the lifter lock out.

Table 2. The rhythm of the movement (t₁/t₂) and peak velocity ($v_{peak}$) of the barbell depending on the value of the load (70% 1RM, 80% 1RM, 90% 1RM, 100% 1RM, and 70 – 100% 1RM).

<table>
<thead>
<tr>
<th>Weight of the bar</th>
<th>70% 1RM</th>
<th>80% 1RM</th>
<th>90% 1RM</th>
<th>100% 1RM</th>
<th>70% 1RM</th>
<th>80% 1RM</th>
<th>90% 1RM</th>
<th>100% 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>t₁/t₂</td>
<td>t₂/t₁</td>
<td>t₁/t₂</td>
<td>t₂/t₁</td>
<td>V_{peak} [m/s]</td>
<td>V_{peak} [m/s]</td>
<td>V_{peak} [m/s]</td>
<td>V_{peak} [m/s]</td>
</tr>
<tr>
<td>T.T.</td>
<td>1.53</td>
<td>1.36</td>
<td>1.11</td>
<td>0.79</td>
<td>.787</td>
<td>.716</td>
<td>.368</td>
<td>.245</td>
</tr>
<tr>
<td>Ł.M.</td>
<td>1.73</td>
<td>1.89</td>
<td>1.73</td>
<td>1.24</td>
<td>.549</td>
<td>.502</td>
<td>.424</td>
<td>.197</td>
</tr>
<tr>
<td>M.P.</td>
<td>2.25</td>
<td>1.96</td>
<td>1.53</td>
<td>1.23</td>
<td>.569</td>
<td>.517</td>
<td>.326</td>
<td>.203</td>
</tr>
<tr>
<td>A.G.</td>
<td>2.46</td>
<td>1.97</td>
<td>1.61</td>
<td>1.02</td>
<td>.696</td>
<td>.491</td>
<td>.271</td>
<td>.142</td>
</tr>
<tr>
<td>Ł.J.</td>
<td>2.13</td>
<td>1.50</td>
<td>0.92</td>
<td>0.61</td>
<td>.449</td>
<td>.429</td>
<td>.270</td>
<td>.096</td>
</tr>
<tr>
<td>D.L.</td>
<td>1.58</td>
<td>1.24</td>
<td>1.25</td>
<td>0.47</td>
<td>.619</td>
<td>.311</td>
<td>.231</td>
<td>.149</td>
</tr>
<tr>
<td>P.K.</td>
<td>0.95</td>
<td>0.90</td>
<td>1.04</td>
<td>0.28</td>
<td>.471</td>
<td>.421</td>
<td>.309</td>
<td>.202</td>
</tr>
<tr>
<td>M.Sz.</td>
<td>1.35</td>
<td>1.04</td>
<td>0.93</td>
<td>0.38</td>
<td>.807</td>
<td>.753</td>
<td>.250</td>
<td>.142</td>
</tr>
<tr>
<td>B.M.</td>
<td>1.41</td>
<td>1.07</td>
<td>0.84</td>
<td>0.70</td>
<td>.571</td>
<td>.458</td>
<td>.338</td>
<td>.232</td>
</tr>
<tr>
<td>J.M.</td>
<td>1.23</td>
<td>1.18</td>
<td>1.17</td>
<td>0.60</td>
<td>.566</td>
<td>.517</td>
<td>.294</td>
<td>.225</td>
</tr>
<tr>
<td>K.K.</td>
<td>1.04</td>
<td>0.89</td>
<td>0.61</td>
<td>0.49</td>
<td>.494</td>
<td>.313</td>
<td>.243</td>
<td>.248</td>
</tr>
<tr>
<td>G.S.</td>
<td>1.42</td>
<td>1.10</td>
<td>0.72</td>
<td>0.52</td>
<td>.442</td>
<td>.394</td>
<td>.148</td>
<td>.136</td>
</tr>
<tr>
<td>P.H.</td>
<td>1.57</td>
<td>1.51</td>
<td>1.16</td>
<td>0.56</td>
<td>.660</td>
<td>.384</td>
<td>.180</td>
<td>.196</td>
</tr>
<tr>
<td>M.O.</td>
<td>1.60</td>
<td>1.34</td>
<td>0.77</td>
<td>0.48</td>
<td>.658</td>
<td>.493</td>
<td>.259</td>
<td>.224</td>
</tr>
<tr>
<td>J.C.</td>
<td>1.84</td>
<td>1.30</td>
<td>0.87</td>
<td>0.71</td>
<td>.506</td>
<td>.385</td>
<td>.289</td>
<td>.311</td>
</tr>
<tr>
<td>M.S.</td>
<td>2.86</td>
<td>2.28</td>
<td>1.30</td>
<td>1.02</td>
<td>.583</td>
<td>.435</td>
<td>.241</td>
<td>.202</td>
</tr>
<tr>
<td>K.L.</td>
<td>1.53</td>
<td>1.44</td>
<td>0.92</td>
<td>0.55</td>
<td>.411</td>
<td>.320</td>
<td>.277</td>
<td>.265</td>
</tr>
<tr>
<td>K.B.</td>
<td>1.21</td>
<td>0.89</td>
<td>0.68</td>
<td>0.36</td>
<td>.547</td>
<td>.314</td>
<td>.157</td>
<td>.203</td>
</tr>
<tr>
<td>T.S.</td>
<td>1.63</td>
<td>1.33</td>
<td>1.01</td>
<td>0.37</td>
<td>.599</td>
<td>.468</td>
<td>.218</td>
<td>.230</td>
</tr>
<tr>
<td>S.S.</td>
<td>1.44</td>
<td>1.22</td>
<td>0.93</td>
<td>0.58</td>
<td>.301</td>
<td>.286</td>
<td>.177</td>
<td>.133</td>
</tr>
<tr>
<td>Mean</td>
<td>1.64</td>
<td>1.37</td>
<td>1.03</td>
<td>0.65</td>
<td>.564</td>
<td>.454</td>
<td>.264</td>
<td>.199</td>
</tr>
<tr>
<td>± SD</td>
<td>0.474</td>
<td>0.390</td>
<td>0.294</td>
<td>0.280</td>
<td>.123</td>
<td>.124</td>
<td>.070</td>
<td>.053</td>
</tr>
</tbody>
</table>

* t₁ – the duration of the descent phase; t₂ – the duration of the ascent phase; $v_{peak}$ – peak of the velocity of the barbell

Table 3. The duration of the descent phase and the average power depending on the value of the load (70% 1RM, 80% 1RM, 90% 1RM, 100% 1RM, and 70 ÷ 100% 1RM).

<table>
<thead>
<tr>
<th>The weight of the bar</th>
<th>70% 1-1RM</th>
<th>80% 1-1RM</th>
<th>90% 1-1RM</th>
<th>100% 1-1RM</th>
<th>70% 1-1RM</th>
<th>80% 1-1RM</th>
<th>90% 1-1RM</th>
<th>100% 1-1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>t [s]</td>
<td>t [s]</td>
<td>t [s]</td>
<td>t [s]</td>
<td>P_{max} [W]</td>
<td>P_{max} [W]</td>
<td>P_{max} [W]</td>
<td>P_{max} [W]</td>
</tr>
<tr>
<td>T.T.</td>
<td>1.16</td>
<td>1.17</td>
<td>1.17</td>
<td>1.26</td>
<td>-194</td>
<td>-203</td>
<td>-195</td>
<td>-245</td>
</tr>
<tr>
<td>Ł.M.</td>
<td>1.45</td>
<td>1.68</td>
<td>1.80</td>
<td>1.73</td>
<td>-160</td>
<td>-232</td>
<td>-236</td>
<td>-193</td>
</tr>
<tr>
<td>M.P.</td>
<td>2.70</td>
<td>2.29</td>
<td>2.05</td>
<td>2.42</td>
<td>-205</td>
<td>-217</td>
<td>-234</td>
<td>-275</td>
</tr>
<tr>
<td>A.G.</td>
<td>1.92</td>
<td>1.89</td>
<td>2.09</td>
<td>1.88</td>
<td>-164</td>
<td>-240</td>
<td>-218</td>
<td>-292</td>
</tr>
<tr>
<td>Ł.J.</td>
<td>2.15</td>
<td>1.52</td>
<td>1.17</td>
<td>1.31</td>
<td>-201</td>
<td>-265</td>
<td>-247</td>
<td>-243</td>
</tr>
<tr>
<td>D.L.</td>
<td>1.26</td>
<td>1.07</td>
<td>1.30</td>
<td>1.09</td>
<td>-307</td>
<td>-313</td>
<td>-324</td>
<td>-370</td>
</tr>
<tr>
<td>P.K.</td>
<td>1.06</td>
<td>1.02</td>
<td>1.19</td>
<td>0.99</td>
<td>-134</td>
<td>-222</td>
<td>-269</td>
<td>-272</td>
</tr>
</tbody>
</table>

* It is the scientific designation of the point where the initial velocity of the barbell as it blasts off the chest has decreased the most, before it starts to increase again until the lifter lock out.
The type of bench press based on the critical...

Table 4. The duration of the ascent phase (t) and the average power ($P_{\text{mean}}$) depending on the value of the load (70% 1RM, 80% 1RM, 90% 1RM, 100% 1RM, and 70 ÷ 100% 1RM).

<table>
<thead>
<tr>
<th>Subject</th>
<th>70% 1RM</th>
<th>80% 1RM</th>
<th>90% 1RM</th>
<th>100% 1RM</th>
<th>70% 1RM</th>
<th>80% 1RM</th>
<th>90% 1RM</th>
<th>100% 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.T.</td>
<td>0.76</td>
<td>0.86</td>
<td>1.05</td>
<td>1.60</td>
<td>332</td>
<td>317</td>
<td>280</td>
<td>226</td>
</tr>
<tr>
<td>Ł.M.</td>
<td>0.84</td>
<td>0.89</td>
<td>1.04</td>
<td>1.40</td>
<td>304</td>
<td>326</td>
<td>312</td>
<td>283</td>
</tr>
<tr>
<td>M.P.</td>
<td>1.20</td>
<td>1.17</td>
<td>1.34</td>
<td>1.96</td>
<td>310</td>
<td>370</td>
<td>347</td>
<td>270</td>
</tr>
<tr>
<td>A.G.</td>
<td>0.78</td>
<td>0.96</td>
<td>1.30</td>
<td>1.84</td>
<td>293</td>
<td>277</td>
<td>220</td>
<td>172</td>
</tr>
<tr>
<td>Ł.J.</td>
<td>1.01</td>
<td>1.01</td>
<td>1.27</td>
<td>2.14</td>
<td>210</td>
<td>245</td>
<td>203</td>
<td>126</td>
</tr>
<tr>
<td>D.L.</td>
<td>0.80</td>
<td>0.86</td>
<td>1.04</td>
<td>2.33</td>
<td>275</td>
<td>278</td>
<td>249</td>
<td>119</td>
</tr>
<tr>
<td>P.K.</td>
<td>1.11</td>
<td>1.13</td>
<td>1.14</td>
<td>3.58</td>
<td>185</td>
<td>197</td>
<td>214</td>
<td>78</td>
</tr>
<tr>
<td>M.Sz</td>
<td>0.80</td>
<td>0.85</td>
<td>1.20</td>
<td>3.24</td>
<td>276</td>
<td>303</td>
<td>240</td>
<td>94</td>
</tr>
<tr>
<td>B.M.</td>
<td>0.95</td>
<td>0.97</td>
<td>1.34</td>
<td>2.97</td>
<td>230</td>
<td>259</td>
<td>208</td>
<td>105</td>
</tr>
<tr>
<td>J.M.</td>
<td>1.28</td>
<td>1.25</td>
<td>1.44</td>
<td>2.07</td>
<td>213</td>
<td>251</td>
<td>235</td>
<td>185</td>
</tr>
<tr>
<td>K.K.</td>
<td>1.01</td>
<td>1.19</td>
<td>1.71</td>
<td>2.03</td>
<td>305</td>
<td>282</td>
<td>228</td>
<td>190</td>
</tr>
<tr>
<td>G.S.</td>
<td>1.18</td>
<td>1.08</td>
<td>1.54</td>
<td>2.58</td>
<td>225</td>
<td>247</td>
<td>204</td>
<td>147</td>
</tr>
<tr>
<td>P.H.</td>
<td>1.03</td>
<td>1.16</td>
<td>1.75</td>
<td>2.44</td>
<td>239</td>
<td>234</td>
<td>154</td>
<td>120</td>
</tr>
<tr>
<td>M.O.</td>
<td>0.84</td>
<td>1.14</td>
<td>1.56</td>
<td>2.39</td>
<td>320</td>
<td>274</td>
<td>228</td>
<td>166</td>
</tr>
<tr>
<td>J.C.</td>
<td>1.03</td>
<td>1.18</td>
<td>1.59</td>
<td>1.94</td>
<td>268</td>
<td>255</td>
<td>200</td>
<td>193</td>
</tr>
<tr>
<td>M.S.</td>
<td>0.99</td>
<td>1.15</td>
<td>1.75</td>
<td>2.00</td>
<td>242</td>
<td>229</td>
<td>164</td>
<td>163</td>
</tr>
<tr>
<td>K.L.</td>
<td>1.23</td>
<td>1.37</td>
<td>1.83</td>
<td>2.31</td>
<td>245</td>
<td>249</td>
<td>200</td>
<td>166</td>
</tr>
<tr>
<td>K.B.</td>
<td>1.27</td>
<td>1.88</td>
<td>2.38</td>
<td>4.04</td>
<td>201</td>
<td>164</td>
<td>143</td>
<td>91</td>
</tr>
<tr>
<td>T.S.</td>
<td>1.02</td>
<td>1.29</td>
<td>2.09</td>
<td>3.36</td>
<td>251</td>
<td>233</td>
<td>165</td>
<td>108</td>
</tr>
<tr>
<td>S.S.</td>
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4. Discussion

The involvement of individual motor units of the muscles as well as the obtained training effects depend on the way the exercise is performed. For practical reasons, it is important to determine the manner in which the desired strength exercises are carried out during a bench press. The way the flat bench press is performed should lead to achieving the intended objective. Muscle growth is the goal of a bodybuilder. During the bench press, the powerlifter aims for the best results. The characteristics of velocity or power can be presented differently for bodybuilders (Figure 1 and 2) and for powerlifters (Figure 3 and 4).

However, the ability to develop high force values, especially for the power of movement, is a prerequisite for high performance in most sports events [8]. For example, performing faster Olympic lifts and using smaller weights provides the possibility for creating a greater power flow to the barbell than is possible in powerlifting. The peak power that flows into the bar when powerlifting fluctuates between 370 and 900 W, while the peak power flowing to the barbell in the Olympic lifts is very often higher than 4000 W [9]. This is why, Olympic lifts are often used for training “explosive” movements and Olympic weightlifters are able to develop mechanical power of the whole body more than other athletes [10].

While assessing the bench press, mechanical power is particularly useful. The aforementioned statement was noticed by Drinkwater et al. [11]. Mechanical power was measured by examining the level of fatigue, based on the decrease in the peak power in the series of the free weight bench press movements. Developing high values of power is particularly important for those sports events in which the force is developed at a high speed of movement (strength-speed sports). During strength and conditioning tests, mechanical power determines

<table>
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<th>Subject</th>
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</tbody>
</table>

Bold font refers to participants of Group 1 (subjects who lifted the barbell at a slower tempo and did so at small values of the average power) and Group 2 (subjects who quickly lifted the barbell and did so at high values of the average power) in bench press with a load 70% ÷100% 1RM.
The type of bench press based on the critical...

Fig. 1. Immediate velocity curves of the barbell depending on the weight of the barbell (70% to 100% 1RM; the subject G.S.).

Fig. 2. Immediate mechanical power curves of the barbell depending on the weight of the barbell (70% to 100% 1RM; the subject G.S.).

the intensity of the effort. With reference to Hamar [8], power considered as the composition of force and speed may be better understood as an indicator characterizing strength abilities rather than as a maximum weight to often be used (1RM).

The impact of the increased load of the barbell on the duration of the ascent phase and the values of the average mechanical power during the flat bench press, was clearly visible in the performances of both the bodybuilder and powerlifter [12]. When the weight of the barbell
Fig. 3. Immediate velocity curves of the barbell depending on the weight of the barbell (70% to 100% 1RM; the subject M.S.).

Fig. 4. Immediate mechanical power curves of the barbell depending on the weight of the barbell (70% to 100% 1RM; the subject M.S.).
increased, the duration of the ascent phase increased and the value of the average power decreased. The decrease in the average power noted strictly when the load is made heavier was also confirmed by Hamar [8]. It is probably the above mentioned increased time of the lifting phase which caused a change in the rhythm of the bench press. The indicator of the rhythm of the movement defined quantitatively, decreased along with the load increase.

The degree of dependence between the average values of the mechanical power during the ascent phase and the duration of this phase was determined by the Pearson correlation coefficient. The obtained values of this coefficient for different loads show the strong relationship between these parameters. It means that while trying to lift the bar as quickly as possible, a high average power is developed. This statement also applies to the speed used to lift the barbell.

The shape of the velocity and power curves show a very strong resemblance (Figures 1 and 2; Figures 3 and 4). The shape of the power curve depends on both the force and the velocity \( P = F \times v \). Although, velocity has greater influence because of the fact that the force applied to the barbell is calculated according to the formula: \( F = m \times (g + a) \). In this equation, the acceleration value \( a \) is at least an order of magnitude and sometimes, two orders smaller than the gravitational acceleration \( g = 9.81 \text{m/s}^2 \). Therefore, with regard to the force applied to the barbell, the static element clearly dominates, i.e. the force required to balance the weight of the barbell. Considering the similar characteristics of velocity and mechanical power, a similar dependence concerning both the average speed during the lift phase and the time of this phase is to be expected.

The aforementioned phenomenon is similar in other movement activities, especially those in which, as it was mentioned in the introduction, muscle actions of the stretch-shortening cycle (e.g. in jumping) are used. If possible, the exercises using the SSC should be given priority in strength training, owing to the fact that achieving higher values of the maximal strength and power is likely to occur [13-17]. In practice, sport exercises that make use of the SSC are very common, and at the same time, the exercises constitute an integral part of natural human movements.

As sports experiences show, it is preferred that the execution of the ascent phase in the bench press be faster (as fast as possible) so as to avoid a “sticking point”. A sticking point was not present at 70% and 80% 1RM loads but it was clearly visible at 90% and 100% 1RM loads (Figure 1) [18-20]. The appearance of the sticking point may be the result of an inadequate angle of the muscle pulling the bone. The angle of the pull is fundamental (crucial) for the linear and angular effects of the muscle force. These muscle-force pulls are conveniently arranged into two directions, i.e. longitudinal and rotational components. Only the component itself working towards the bone at right angles (perpendicular to the bone; rotational, turning component) creates a torque that contributes to potential rotation. It is probable that rotational components have very small values during the ascent phase taking place at inconvenient angles to the shoulder and elbow joints. According to Knudson [5], “the angle of the joints affects the torque that the muscle group is capable of producing because of variations in moment arm, muscle angle of pull, and the force–length relationship of the muscle”. Thus, although the muscles produce large forces, only some of them (the rotational component) affect the rotation of the joint, and therefore have impact on the linear kinematics of the barbell.

With the use of cluster analysis, all subjects were included into one of the groups based on the standardized time of the lift phase and the standardized average power developed in the phase of the bench press.

Group 1 consisted of those subjects who lifted the bar at a slow tempo and did so at small values of the average power. This group of participants would be suitable for bodybuilding. The first group included 11 participants.

Group 2 included subjects who quickly lifted the bar and did so at high values of the average power. This group of participants would be suitable for powerlifting and certainly for weightlifting. The second group included 9 participants.

5. Practical applications

1. The results of the following study indicate that the sticking point is characteristic not only for the velocity curve \( v(t) \) but also for the power curve \( P(t) \). This indicates that, in certain cases, the evaluation of the bench press can be performed either on the basis of the power curve or the velocity curve. This evaluation is important because the sense of sight only allows us to approximately differentiate the speed.

2. A much more interesting implication is that irrespective of the size of the load, a significant negative correlation between the average power of the lifting phase and the duration of this phase was noted. On the one hand, the mechanical power is not visually differentiated. On the other hand, a longer or shorter lifting of the barbell can be noted even by an untrained observer (an athlete or a coach).

3. Cluster analysis based on both the length of the lifting phase and the average power in this phase classifies the participants into two groups. The first group concerns the participants who primarily want to increase the mass of their muscles (bodybuild-
ers). The second group included those mainly interested in getting the best results in the bench press (weightlifters, recreational lifters exercising for their own purposes).

4. If it is possible, “make your moves as fast as you can acting at the same time against the force of gravity”.

Acknowledgements

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References


Summary

**Aim.** Aging has been widely observed to be one of the paramount obstacles in social activity routines. Aging-related impairments and their dramatically advancing consequences should draw our attention in order to improve the effective functioning of older people in society. The purpose of this study is to evaluate flexibility in a chosen group of women above the age of 50 in Poland, in the Kujawsko-Pomorskie Voivodeship.

**Material and methods.** 3,413 women, aged 50-80 years participated and were analyzed. The subjects were divided into six age groups. The BMI was calculated for each participant. All women were subjected to three flexibility tests, the findings of which were later analyzed statistically.

**Results.** All participants completed the study. The results of the “Back Scratch” and “Shoulder Flexibility” tests showed deterioration of flexibility in women depending on age, from -0.15 cm to -6.69 cm (“Back Scratch”) and from 71.53 cm to 80.73 cm (“Shoulder Flexibility Test”). In the modified “Sit-and Reach” test the tendency for the results was the same except for the second and third subject age group whose obtained values were higher than in the case of the first one.

**Conclusions.** The test results unmistakably indicate that flexibility diminishes with age. Secondly, both of the evaluating tests must be performed in order to achieve proper global shoulder girdle flexibility evaluation. From the findings of the study, it can be shown that flexibility regression occurs to a greater extent in the upper limbs than in lumbar – pelvic complex.

Introduction

Over the past several decades in Poland, as well as in the majority of European countries, society aging has been observed to be advancing to a large extent. There are numerous conditions making physical fitness within society dramatically impaired. Specifically, for instance prolonged periods of sitting (i.e. sedentary behavior) can seriously compromise adults’ health [1]. There are an overwhelming number of other aspects facilitating the decline in the physical fitness of older people.

This process should draw our attention due to the vital consequences it causes in our health. In relation to this fact, physical fitness level determination is needed to better define the determinant of these people’s functional independence. According to statistics reports, the post-working population number will increase in Poland from 6.5 million in 2011 to 11.5 million in 2050 [2]. Using the
data from the Central Statistic Office, estimated lifespan is going to be prolonged between 2010 and 2035 for men from the current 71.4 years to 77.1 years. However, in the case of women, these numbers are projected to change from 79.8 years to 82.9 years. Additionally, studies are also indicative of dramatic surge in growth of the population above the age of 80 from 3.3% of the total number of people in 2010 to 7.1% in 2035, which is a staggering increase by 115%. Demographic simulations have been shown to result in the growing participation of women in the above 65 population, namely 54% by 2035, which means that it deserves particular attention to be familiarized with physical fitness of this sex [3].

To differentiate and identify the complexity and inevitability of the aging process, one needs to properly determine how vital the physical fitness level in older people is. Undeniably, physiological function declines with age. Yet, its attribution to biological or social factors following older age is not completely explained [4]. Thus, knowledge gathered during conducting studies and based on the outcome of the tests will make it possible, early enough, to predict the functional impairments of the above mentioned population and, therefore, take actions to effectively diminish those problems by introducing preventive programs diminishing or protecting people from disabilities.

Various studies indicate that the most paramount aspects contributing to functional efficiency in older people are flexibility, muscle strength as well as cardio respiratory efficiency. Along this line, it is frequently desired by clinicians to choose the most reliable and valid tests, prepared with as little equipment and time as possible [5]. As such, in an attempt to facilitate further possibilities to eliminate functional limitations and the risk of falls, this study focuses on the issue of flexibility. One widely accepted viewpoint indicates that due to maintaining appropriate muscle fiber length, and therefore ensuring full movement range in joints, certain disabilities can be limited. In relation to this, the main purpose of this study is to evaluate flexibility in a chosen group of women above the age of 50 in Poland, in the Kujawsko-Pomorskie Voivodeship.

Material and methods

The subject population consisted of 3,413 women, tested in 2007-2011. The whole group was divided into six age groups: 50-54, 55-59, 60-64, 65-69, 70-74 and 74-79 years. (Table 1). The participants took part in the Senior Physical Activity Regional Program. Testing was conducted in 34 towns of the Kujawsko-Pomorskie Voivodeship: in Aleksandrów, Barcin, Brodnica, Brzoza, Bydgoszcz, Dąbrowa, Gąsawa, Gniewkowo, Grudziądz, Inowrocław, Kcynia, Koronowo, Lisewo, Lubicz, Labiszyn, Mrocza, Nakło, Nowa Wieś Wielka, Nowe, Radziń, Rogowo, Rynarzewo, Rypin, Sławęcin, Służewo, Szubin, Świecie upon Osa, Tłuchów, Tupadły, Unisław, Włoclawek, Zamość and Żnin. The sample of participants was chosen from a population of women aged 50-80. All subjects taking part in the study were obliged to provide informed consent prior to participation as well as undergo qualification tests conducted by a medical practitioner accompanied by a Master of Nursing. The purpose of medical examination was to evaluate the subject’s general health condition and eliminate those who, due to health problems, were not able to participate in physical exercises untypical for rehabilitation. The examination included an interview, blood pressure and heart rate measurement, ECG, lung auscultation, reflex, balance and color vision examining, followed by measurement of height, body mass, waist and hips circumferences. On this surface, the factors most specifically taken into consideration were circulatory-system and musculoskeletal efficiency. Chronic circulatory, respiratory and skeletal system diseases as well as neurological diseases were the criterion for exclusion from physical fitness examination. Having consulted the specialists, women with pharmacologically controlled hypertension and diabetes were allowed to participate in the study. After functional fitness levels were assessed for all subjects, they were required to attend testing sessions conducted by a Master of Physical Therapy in order to measure their physical fitness level. Each functional testing was performed in the afternoon, in the same order for every individual subject. Prior to testing, the tester gave each subject instructions and showed them how each exercise should be performer. Testing was conducted in rooms which were up to safety standards, at the temperature of 18-22°C, with a nurse present in the room. To evaluate flexibility of women participating in the study, three tests were performed. The first test – “Back Scratch” - was taken from the battery of tests created by Roberta Rikli and Jessie Jones [6]. The second test was a modified “Sit-and-Reach” test. During this exercise the subject had a lumbar spine section and posterior group of thigh muscle flexibility evaluated by doing this test in an “I sit” position and without bending the knee shifting on a platform an indicator with a centimeter graduation mark as far ahead as possible [7]. Subjects were afterwards required to perform the third additional “Shoulder Flexibility” test which shows the elasticity state of the whole shoulder joint in the sagittal plane. During this test the subjects lifted a stick over their head to behind the back with straight elbows, maintaining the hand grip on the object. The tests were repeated, moving the hands closer together each time until the movement cannot be completed. The score was recorded as the minimum distance between the hands [8].
Results

Every one of the subjects completed all three tests. In the case of the modified “Sit-and-Reach” test, which was used to evaluate the flexibility of the lumbar spine section as well as the posterior group of the thigh muscles, the longest mean distance (6.44 cm ± 7.35) was obtained by women participants from the 55-59 age groups. The next age group, namely 60-64 years, was only slightly worse yielding the mean value of 6.42 cm ± 7.35. The youngest participants (age group 50-54 years) reached the mean distance of 5.66 cm ± 7.72. The last three age groups had worse and worse results depending on age. As such, the 65-69 age group had a mean distance of 4.86 cm ± 7.22, while the next group (70-74 years): 4.71 cm ± 9.73 achieved by the third age group (60-64 years), 4.71 cm ± 10.04 for the fourth age group (75-79 years): 4.66 cm ± 8.34. (Figure 1). The results show that developments in particular age groups, both in the group with the best outcomes and in the group with the weakest ones, are not statistically significant. The percentile ranks for the “Sit-and-Reach” test for the subjects can be seen in Table 2.

In the case of the “Back Scratch” test, the conclusion can be drawn that the older the subjects being tested the worse the results. The best result was obtained by the first age group (50-54 years) which had a mean value of -0.15 cm ± 8.68, whereas the last age group (75-79 years) obtained the worst mean result of -6.69 cm ± 12.54. The rest of the mean results were as follows: -1.77 cm ± 9.73 for the subjects aged 55-59 years, -1.98 cm ± 9.94 achieved by the third age group (60-64 years), -3.97 cm ± 10.04 for the fourth age group (75-79 years):

Table 1. Characteristics of the subjects

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</table>

Figure 1. The data show the level of flexibility in six age groups with division into: ◆ -10 percentage, ▲ - 50 percentage, ■ - 90 percentage. The trend line shows a decrease in flexibility of the lower lumbar spine with the following age groups, occurring one after another.
(65-69 years) and -4.95 cm ± 9.78 for subjects aged 70-74 years (Figure 2). The figure shows that the best test results in successive age groups are not statistically significant. The percentile ranks for the “Back Scratch” test for the subjects can be seen in Table 3.

The last component of the study – the “Shoulder Flexibility” test – confirmed age as being one of the factors deteriorating people’s mobility abilities. The best mean value of 71.53 cm ± 14.7 was achieved by the first age group (50-54 years). Women from the rest of the study

<table>
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Table 2. Percentile Ranks for the “Sit and Reach” test

Figure 2. The data show the level of flexibility in six age groups with division into: ◆ -10 percentage, ▲ - 50 percentage, □ - 90 percentage. The trend line shows a decrease in flexibility of the whole shoulder joint in the sagittal plane with the following age groups, occurring one after another.
groups had worse results depending on age. The worst mean distance was obtained in the last age group (75-79 years) and it was 80.73 cm ± 11.92. Figure 3 shows that the outcomes of particular women’s age groups achieving the weakest results are not statistically significant. The percentile ranks for the “Shoulder Flexibility” test for the subjects can be seen in Table 4.

### Table 3. Percentile ranks for the “Back Scratch” test

<table>
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<td>853</td>
<td>1131</td>
<td>884</td>
<td>350</td>
<td>145</td>
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</tbody>
</table>

### Discussion

Aging is an inevitable process in human life and by causing profound changes in body composition, it contributes to debilitating conditions in older persons. Bearing that in mind, functional fitness and flexibility are likely to play a crucial role in maintaining vitality and mobil-
Impaired joint flexibility may have a highly negative impact on performing everyday activities. Therefore, there are some programs whose designers focused on regular physical activity enabling the improvement of fitness parameters [9].

Flexibility is a feature of a movement organ allowing for the amplitude of movement in a certain joint to be kept within a wide range as far as possible by this joint’s physiology. Furthermore, this feature is dependant on the tension of muscles participating in this joint’s activity, tendon and ligament elasticity, age and sex [10].

It is easy to notice in the “Shoulder Flexibility” test that there is a clear downslide with passing age within the population of women with the best results. Whereas in the population of women achieving the weakest results there is also a downslide, however of no statistical value. This proves that with successive age groups, the difference between women achieving the best results and those having the weakest results is dwindling. Which is caused by the decrease in the population of persons obtaining the best results. It is assumed that the persons achieving the weakest results were employing the muscle groups responsible for glenohumeral and scapular joints rotation to a very small extent in everyday life, which along with age, made it possible for their activity to be diminished even further. The situation lends support to the idea of how important the adversarial muscle group stretching and strengthening exercises are in relation to aging of the organism.

The “Back Scratch” test findings show that in the group of women achieving the weakest results, the downslide related to aging is very strong, whereas in the group of women having the best results, decrease of the values achieved in the test are not statistically significant. While evaluating this test, we can observe the increase of the difference between the weakest and best results in particular age groups, due to the fact that the number of persons obtaining the weakest results is growing. This is most probably due to fact that women achieving very good test results in younger age groups continue this kind of activity with age since it accompanies them in numerous everyday tasks, such as washing one’s back or fastening a bra. On the other hand, nevertheless, women from the youngest tested groups who obtained the weakest results were most probably more frequently using other people’s help doing everyday routine activities.

The findings of the “Sit-and-Reach” test show that both in the group of women having the best results and in the group with the weakest results regarding the whole tested population, there was a deterioration of the results in relation to aging of the tested groups. However, the differences in the subsequent age groups were not statistically significant, which proves that the diminishing of the tested values with age may be affected by the changeability of the population. As well as the size of the group being subjected to the test which in this publication is not homogenous in particular age groups. The weaker results achieved with age is also generated by independent factors, such as intervertebral disc dehydration and its complete degeneration on L4 and L5 levels, which influences the diminishing of intervertebral space and this in turn makes the movement range of the whole section smaller. Osteophytes are also being formed and in this way they stiffen the spine and structurally diminish the range of its flexion.

Nonetheless, the overall responsibility of the posterior thigh muscle group is shown here in relation to the magnitude of flexion in this particular test. Thus, along this line, further efforts to improve the flexibility of this section should be taken into consideration.

Table 4. Percentile ranks for the “Shoulder Flexibility” test

<table>
<thead>
<tr>
<th>% Rank</th>
<th>50-54</th>
<th>55-59</th>
<th>60-64</th>
<th>65-69</th>
<th>70-74</th>
<th>75-79</th>
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<tr>
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<td>20</td>
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<tr>
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<td>1131</td>
<td>884</td>
<td>350</td>
<td>145</td>
<td>50</td>
</tr>
</tbody>
</table>
It must be accentuated that this study is known to be the only one in Poland examining such a numerous group of subjects (3413 women) using three flexibility tests. Other studies in Poland, although of great importance, concentrate on much smaller subject groups and are frequently related to different aspects.

To take a proper approach in developing appropriate senior mobility improving programs, one must first focus on the elderly people’s will to exercise. According to L. Puggaard [11], physical strength exercises are the most effective for older people, especially for women. In the author’s study, all female—participants completed the tests. In W. Makula’s study [12], a wide selection of opinions was presented by female—subjects. They either disapproved of physical strength or treated it as the most crucial factor. Generally, though, they were aware of the importance of physical fitness with advancing age.

As far as comparing the study results is concerned, the subject group examined by K. Roźek et al. [13] consisted of 50 persons, 22 men and 28 women. The age mean of women was 66.6 years and the BMI for this subject group had a value of 29. They obtained -6.5 cm in the “Sit-and-Reach” test, while -7.5 cm in the “Back Scratch” test. These were the results achieved before training, as in the author’s study. Whereas Z. Ignasiak et al. [14] reported completely different values while examining the subject group of women consisting of 138 persons, with the mean age of 62.54 years, the BMI 27.37. Their results were as follows: 7.38 cm in the “Sit-and-Reach” test and 0.33 cm in the “Back Scratch” test.

There are various studies reporting and examining the association between advancing aging and functional fitness. However, despite using the same flexibility tests, the results tend to indicate great differences between similar age groups in different countries. The last age group in the present study (75-79 years) obtained the value of -6.69 cm in “Back Scratch” test. Two completely different results stemmed from other studies. J. Grześkowiak and D. Wielinski [15] were examining a subject group of women with a mean age 76.8 years and received the value of -15.5 cm, while, in comparison, Rikli and Jones’s research [16] showed the value of -1.9 cm during the same test. It is obvious that the differences are staggering. Comparing the results of the “Sit-and-Reach” test, J. Grześkowiak and D. Wielinski [15] reported -1.6 cm, Rikli [16] -1.3 cm, and in this study this value was 4.66 cm. With respect to flexibility tests, it is sometime important to consider sometimes great differences in results when interpreting them. In their study concerning men aged 60-79, Z. Ignasiak et al. [17] found no statistically significant differences between age groups in relation to most measured parameters. Another study conducted by N. Takeshima et al. [18] also showed no significant changes in flexibility in the “Back Scratch” and “Sit-and-Reach” tests. Various data also implicate differentiation between gender groups. Specifically, J.M. Miotto et al. [19] indicated in their study that the women subjects reached about 4 inches further than the men in the “Back Scratch” test.

The main aim of this study is to evaluate flexibility in a large group of women over 50 years old in order to effectively stimulate creating senior mobility improvement programs. There are reports in medical literature on short courses of functional exercise training being a crucial factor in improving various components contributing to advancing older adults’ functional fitness [20]. Undeniably, maintenance of flexibility in a best possible condition with advancing age is highly critical. After all, simple everyday routines consist of numerous movements that we do not pay attention to unless they become impaired. As R. Kostić et al. [21] in their study noticed, that the “Back Scratch” test shows how important this kind of mobility is in, for example, reaching someone’s seatbelt in the car or reaching things placed above the shoulders. Whereas the “Sit-and-Reach” test may reflect everyday activities, such as getting out of the bathtub or tying shoelaces...

As stated previously, the use of flexibility tests helps to assess the possibilities for reducing age-related mobility limitations. One of the conclusions drawn after conducting these tests in the study by N. Takeshima et al. [18] was selecting single strategy exercise programs addressing multiple components of fitness improvement. Flexibility measurements should be conducted not only by doctors, physical therapists, but also by seniors’ coaches since their decline may appear to be one of the factors causing spinale pains. Whereas- ischiocrural muscle shortening may lead to future lumbar spine pains because muscle contracture of the posterior thigh muscle group has influence, on lumbar spine forced compensation through the pelvis, which might result in its overload [22].

Flexibility improvement together with training which enhances muscle strength and sharpens proprioceptive functions, affects a faster and more efficient reaction to a change of a body position in space and allows a faster return to a supporting plane after being off balance. Better movement control facilitates preventing falls which may lead to breaking bones and, consequently, further limitations [23,24].

Acknowledgments
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Conflict of interest
The authors declare they have no conflict of interest.
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15. Grześkowiak J, Wielinski D: Comparison of selected physical activity parameters of over 65-year-old women researched with the method of the fullerton functional fitness test with population researched in the USA by Rikli and Jones., Antropomotoryka 2009; Nr 45: 77-82.

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OXIDATIVE STRESS AND TRAINING

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Key words: reactive oxygen species, oxidative stress, exercise, training

Abstract

Introduction. Reactive oxygen species (ROS) are produced in the body under physiological conditions. ROS are involved, among others, in cell signaling. Imbalance between ROS creation and their neutralization is called oxidative stress and is characterized by the uncontrolled oxidation of lipids, proteins or DNA. Research indicates that increased production of ROS and prooxidative-antioxidant imbalance may occur during intense exercise.

Aim. The aim of the study was to determine the effect of different sports on the prooxidative-antioxidant blood status among highly trained athletes on the basis of a review of scientific literature.

Material and methods. A review of scientific literature was done from 2011 to June 2015 using the databases: Medline, PubMed and Google Scholar web browser. The review included original works which contained the following expressions in the text of their abstracts: “oxidative stress and sport”, “oxidative stress and athletes”, “oxidative stress and endurance”, “free radicals and sport”, “free radicals and athletes”, “free radicals and endurance”. 570 scientific papers were selected in total.

The analysis excluded the impact of work on the nutrition strategy, vitamin and mineral supplementation, sport nutrition supplements that could affect the level of oxidative stress, and in which a group of test persons were untrained and casual exercisers. Criteria fulfilled 20 scientific papers (original), which present the results of studies involving 458 players individual sports and team, among others: footballers, volleyball, handball, players: martial arts, tennis, triathlon, swimming.

Results. Numerous studies have shown that an increase in ROS production as a result of physical exercise is conditioned by among others: degree of fitness competitor, gender and intensity, duration and type of exercise.

Conclusions. Physical training models the efficiency of the antioxidant defense mechanisms of the body by increasing the activity of antioxidant enzymes such as catalase and superoxide dismutase, resulting in increased levels of total antioxidant status in plasma and increase the share of glutathione antioxidant capacity in trained athletes.

Summary. ROS synthesis depends on the type of muscle work, intensity and duration of exercise. The improvement in exercise capacity is an effective way to improve antioxidant defense system, and thus to stay healthy.

Introduction

Oxygen is an essential element for the proper conduct of oxidative phosphorylation. About 2-5% of the oxygen absorbed by the body is converted into reactive oxygen species (ROS), which may damage the biologically active compounds, in particular proteins [1]. ROS include, inter alia, superoxide anion (O₂⁻), converted to the representative body of free radicals and hydrogen peroxide - H₂O₂, the most important precursor of free radicals [2, 3]. Oxygen free radicals belonging to ROS include at least one oxygen atom and have at least one or more unpaired electrons. ROS has a high reactivity and easily reacts chemically with cellular components. ROS interact with cells or signal molecule relay, which indicates that they play an important role in the proper
functioning of the whole cell [3]. They are involved in many processes, including muscle work, secretion of hormones, the functioning of the immune system, or in the regulation of vascular tone [4]. On the other hand, ROS excess produces negative effects in the body as oxidation of macromolecules: proteins, fats and nucleic acids. Excess of ROS is observed in the course of some chronic non-contagious diseases (diabetes, cancer, atherosclerosis) [4]. The phenomenon of imbalance between the production of ROS and their neutralization is called oxidative stress.

The level of reactive oxygen metabolites can be measured by the d-ROM test (diahronics Reactive Oxygen Metabolic test). Quantitation of d-ROM is modified depending on the plasma concentrations of hydrogen peroxide (H$_2$O$_2$), peroxynitrite (ONOO$^-$) and hydroperoxides (ROOH) [5].

The ability of reactive oxygen species synthesis belongs to neutrophils, which play a fundamental role in immune response. They are considered the first line during the defense against invading pathogens, which are destroyed as a result of the production of cytotoxic reactive oxygen species [6]. Oxidative burst - OBA (Oxidative Burst Activity) is an indicator showing the ability of ROS production by neutrophils [6].

Free radicals are neutralized by antioxidant defense of the body including enzymatic and non-enzymatic mechanisms. The enzymatic antioxidant defense system creates enzymes, among which we can distinguish superoxide dismutase (SOD) - an enzyme that catalyzes the reaction dismutation of the superoxide radical to hydrogen peroxide, catalase (CAT) - decomposing hydrogen peroxide into water and oxygen, peroxidase, glutathione peroxidase (GPx) - converting reduced glutathione (GSH) into oxidized glutathione (GSSG), and reducing hydrogen peroxide to oxygen [7] or glutathione reductase (GR), which catalyzes the reduction of glutathione (GSSG to GSH) in the presence of NADPH which is oxidised to NADP$^+$ [8].

Reduced glutathione GSH is a naturally occurring endogenous antioxidant. By reacting with reactive oxygen species to protect the thiol groups of proteins against oxidation by ROS. Evaluation of the GSH/GSSG redox potential is one of method of determining the level of oxidative stress [9]. Bilirubin, in addition to glutathione, is a natural antioxidant in plasma and in cell membranes. The level of total bilirubin (TBIL) significantly increases after intense exercise [10]. Not all endogenous antioxidants are characterized only by positive action. An example can be uric acid (UA) and nitric oxide (NO). UA is a scavenger of peroxyl, peroxynitrite and hydroxyl radicals. At the same time, the high level correlates with the occurrence of non-infectious chronic diseases (obesity, hypertension, cardiovascular disease or cardiac disease) [10,11]. In contrast, NO secreted by the vascular endothelium against increase of vascular tone plays an important role in physiological processes of the nervous system, both as a signaling molecule and the sodium pump cell modulator. On the other hand, the excess can contribute to the formation of toxic compounds reacting with oxygen, iron or copper [4].

Together, antioxidants determine total antioxidant status (TAS - Total Antioxidant Status), which is the body’s ability to counteract the damage induced by free radicals [12]. Another indicator of the level of oxidative stress is total oxidation potential (TOS - Total Oxidative Status) [13]. In contrast, the index of oxidative stress OSI (Oxidative Stress Index) is estimated on the basis of TOS/TAS, and reflects the balance of oxidative and antioxidant processes in the body [12]. Many studies have used estimated concentrations of malondialdehyde (MDA) as a marker of oxidative stress and the main product of lipid peroxidation [14]. Lipid peroxidation is a process of oxidation, especially polyunsaturated fatty acids included in phospholipids that form the basic building block of biological membranes (mainly phosphatidylethanolamine and phosphatidylcholine) [15]. This leads to the formation of peroxides of such compounds and damage associated with the plasma and mitochondrial membranes. Evaluation of products reacting with thiobarbituric acid (TBARS) is a well-known marker of lipid peroxidation [16]. This process is free radical in nature and occurs rapidly. An additional marker may be fatty acid peroxide (LOOH), which emerges considerably earlier than MDA in one of stages of lipid peroxidation [15]. A relatively sensitive gauge of the size of oxidative stress is the assessment of changes in the level of protein oxidation products. Among them can be distinguished such indicators as AOPP (Advanced Oxidation Protein Products) [17], RCD (Reactive Carbonyl Derivatives) [18].

Exercise contributes to increased production of ROS, which, as it has been shown in numerous studies, has adverse effects, particularly in the case of unprepared tissue [12, 13, 19, 20, 21, 22]. Whether the oxidative stress induced by exercise reveals only harmful effects remains a matter of debate.

Although increased production of ROS induced by exercise is potentially damaging to physiological function, the repeated exposure of the body’s increased production of ROS during regular physical exercise leads to positive adaptive changes in the body. This is manifested in the regulation of expression of gene encoding proteins responsible for the antioxidant defense of the body [7,19]. This was found to increase the activity of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT) in the muscles, liver and heart after intense physical exercise [20].

This adaptation provides protection against ROS during subsequent sessions. A series of high-intensity
exercises by increased production of ROS activates the NF-κB transcription factor by increasing transcription of genes for antioxidant enzymes such as mitochondrial superoxide dismutase (MnSOD) and inducible nitric oxide synthase (iNOS) [23, 24].

Intense aerobic exercise exacerbates oxidative stress and the increase of endogenous antioxidants in untrained persons, whereas in those training, significantly lower levels of oxidative stress are achieved as the result of regular exercise programs [20]. In addition, [25,26], athletes have a higher antioxidant capacity than untrained people, but the capacity is different in different phases of meso and macro-training process [27].

The aim of the study was to determine the effects of different sports on the prooxidative - antioxidant status in the blood among highly trained athletes on the basis of a review of the scientific literature on the subject.

Material and methods

A review of scientific research from 2011 to June 2015 was conducted using the databases: Medline, PubMed and Google Scholar web browser. The review includes original papers, containing the following expressions in their abstracts: “oxidative stress and sport”, “oxidative stress and athletes”, “oxidative stress and endurance,” “free radicals and sport”, “free radicals and athletes,” “free radicals and endurance”.

A total of 570 scientific papers were selected. The analysis excluded the impact of works on nutrition strategy, vitamin and mineral supplementation, sport nutrition supplements and in which the study group consisted of untrained persons and those exercising regularly. The criteria were fulfilled by 20 scientific papers (original), which present the results of studies involving 458 players of individual and team sports, among others: footballers, volleyball, tennis and handball players, athletes doing martial arts, the triathlon and swimming. The average age of the youngest group of athletes included in the analysis was 15.2 ± 0.9 years, and the oldest 37 ± 6.7 years.

The level of oxidative stress and individual sports

Many external stimuli, including physical exercise, increase the number of neutrophils and increase their activity, together with their ability to synthesize reactive oxygen species. The results of the research by Kudoh et al. [6] confirm earlier reports [29] on the positive impact of exercise in increasing the number of neutrophils. The study by Kudoh et al. included 39 men, members of the Nippon Sport Science University judo club. Before and after training (duration: 2 hours, HR 129 ± 12 beats/min), venous blood was collected for biochemical assays. There was a statistically significant increase in OBA after the completion of training, while a statistically significant reduction of phagocytic activity also occurred (Table 1) [6].

Lipid peroxidation is the most common consequence of oxidative stress leadings to an increased level of oxidation products of fatty acids including LOOH and MDA. In their study, Eroglu et al. [21] indicate the level of MDA and activity of sodium in judo competitors and healthy untrained persons. The subjects were exposed to submaximal (75% VO2max), aerobic exercise on a mechanical treadmill.

MDA concentration after exercise significantly increased in both groups of judo competitors by 32.7%, and 15.5% in untrained, but the activity of SOD significantly increased in judo competitors by 13.2% (Table 1). The degree of lipid peroxidation was determined by de Lucas et al. [30] using TBARS as a marker. The authors studied a group of 11 highly trained athletes of different sports who participated in the Multisport Brasil Race, consisting of three disciplines: running - 28.5 km, mountain biking - 42.5 km and kayaking - 17.5 km.

Before and after the race, blood was collected and analyzed, and among others, CAT and TBARS were determined. They found that the CAT activity after exercise did not change, and the level of TBARS increased significantly to 145% (Table 1). In contrast, Rowlands et al. [31] examined long-distance runners after they ran the distance of 894 km in 47 stages, extending over 95 hours (Bruce Trail). TAS was indicated in the athletes blood but the exercise-induced increase was not significant. The statistically significant higher rate of TAS, TOS and OSI, measured during rest, was found in children who trained swimming, as compared to the untrained group of children (Table 1) [13]. Other studies related to the assessment of indicators of oxidative stress among tennis players, and athletes doing karate and wrestling. Research by Knez et al. [5] was conducted among 10 tennis players, who played two friendly matches in two different controlled climatic conditions: indoor court, the temperature of approx. 22°C and humidity of approx. 73%; at a temperature of about 37°C and humidity of approx. 12%, on an outdoor court, with an interval of 72h or 144h. Blood was collected before the warm-up, in the middle of and immediately after each match and 24h and 48h after the game. The d-ROMs test was performed (H2O2, ONOO-, ROOH). The results showed that the concentration of d-ROMs did not show statistically significant changes depending on the environmental conditions, as well as the length of rest after the match.
Table 1. Results – oxidative stress and sports training

<table>
<thead>
<tr>
<th>Authors, year</th>
<th>Trained: discipline, number (n), gender, age, training experience (TE), frequency of training</th>
<th>Control group: untrained (UT), number (n), gender (M, F), age</th>
<th>Applied test (type, duration of exercise, blood collection - BC)</th>
<th>Results – statistically significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulduk et al., 2011 [20]</td>
<td>Volleyball, n=10, F, 20±1.2 years</td>
<td>UT, n=10, F, 19±1.8 years</td>
<td>20-m transfer run, BC before and after exercise</td>
<td>TR after exercise: ↓GSH, ↑MDA, ↑CAT</td>
</tr>
<tr>
<td>Conti et al., 2012 [37]</td>
<td>Triathlon (T), n=10, M, 29.8±8.7 years; Football (FB), n=15, M, 26±0.6 years; Sprinters (S), n=10, M 31.3±6.4 years, TE ≥5 years</td>
<td>none</td>
<td>Treadmill stress test according to Bruce protocol, spirometric test, BC in the morning, fasting state, 12h after mean</td>
<td>CAT: FB &gt; S &gt; T NO: T &gt; FB &gt; S TBARS: S &gt; FB &gt; T</td>
</tr>
<tr>
<td>da Costa et al., 2011 [34]</td>
<td>Football, n=10, M, 18.3±0.7 years</td>
<td>none</td>
<td>Loughborough Intermittent Shuttle Test (LIST): march, sprint, jogging (55%VO2max and 95%VO2max alternately for 90 min: 5x15 min and 3 min interval), BC before, during and after the test</td>
<td>After exercise: ↑Urea, ↑MDA</td>
</tr>
<tr>
<td>Djordjevic et al., 2012 [19]</td>
<td>Handball, n=58, M, 17.3±0.2 years, Training sessions 5 times a week, 1.5 h each</td>
<td>UT, n=37,M, 17.5±0.3 years</td>
<td>Progressive test (until refusal) 2W/kg, load increase every co 3 min by 50W, 60 rev/min, BC before and after exercise</td>
<td>none</td>
</tr>
<tr>
<td>Eroglu et al., 2013 [21]</td>
<td>Judo, n=16, M, 20±1.9 years</td>
<td>UT, n=16, M, 20±1.2 years</td>
<td>Treadmill test,75%VO2max according to Bruce protocol, BC before and after exercise</td>
<td>TR after exercise: ↑MDA, ↑SOD NT after exercise: ↑MDA</td>
</tr>
<tr>
<td>Gökhan, 2013 [12]</td>
<td>Volleyball, n=20, M, 15±1.64 years, TE 2 years, Training sessions 3 x week, lasting 2 h</td>
<td>UT, n=12, M, 15.3±1.2 years</td>
<td>none</td>
<td>TR vs. UT: ↑OSI, ↑TAC, ↑TOS</td>
</tr>
<tr>
<td>Gökhan et al., 2013 [13]</td>
<td>Swimming, n=18, M, 15.2±0.9 years, TE=2 years, Training sessions 3 x week, lasting 2 h</td>
<td>UT, n=18, M, 15.3±1.1 years</td>
<td>none</td>
<td>TR vs. UT: ↑TAC, ↑TOS, ↑OSI</td>
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<tr>
<td>Hadžović-Džuho et al., 2014 [17]</td>
<td>Wrestling (W), n=12, Football (FB), n=14, Basketball (B), n=13, 22.1±4.4 years, TE≥10 years, training sessions min. 6 x week</td>
<td>none</td>
<td>none</td>
<td>MDA: K&gt;Z&gt;P ADPP: K&gt;Z&gt;P ImAnOx: K&gt;P&gt;Z</td>
</tr>
<tr>
<td>Hammouda et al., 2011 [10]</td>
<td>Football, n=12, M, 17.4±0.4 years, Training sessions 4 x week, lasting 2 h</td>
<td>none</td>
<td>RSA Test– 5 x 6s Maximal sprint cycloergometer, BC 7:00 a.m. and 5:00 p.m. before and after exercise</td>
<td>Before exercise in the evening vs. morning: ↑TBIL, ↑UA, ↑TAS After exercise in the evening vs. morning: ↑TBIL, ↑UA, ↑TAS</td>
</tr>
<tr>
<td>Hammouda et al., 2012 [11]</td>
<td>Football, n=18, M, 17.5±0.4 years, Training sessions 4 x week, lasting 2 h</td>
<td>none</td>
<td>30-s Wingate test, BC 10 h before and 3 min after test</td>
<td>After exercise: ↑TBIL, ↑UA, ↑TAS</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Sport/Discipline</td>
<td>Gender, Age, Years</td>
<td>Protocol/Procedure</td>
<td>Oxidative Stress Markers Before/After Exercise</td>
</tr>
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<tr>
<td>Knez et al., 2014 [5]</td>
<td>Tennis, n=10, M, 22.6±4.6 years</td>
<td>None</td>
<td>2 matches (indoor and outdoor) on hard surfaces at interval of 72 or 144 h. BC before, in the middle, immediately after, 24 h and 48 h after the match</td>
<td>↑ ↓ d-ROMs</td>
</tr>
<tr>
<td>Kudoh et al., 2014 [6]</td>
<td>Judo, n=39, M</td>
<td>None</td>
<td>2-hour UEL training sessions - unified exercise loading, BC before and after UEL.</td>
<td>After exercise: ↑ OBA, ↓ PA</td>
</tr>
<tr>
<td>de Lucas et al., 2014 [30]</td>
<td>Various disciplines, n=11, M, 34.3±3.1 years</td>
<td>None</td>
<td>Multisport Brasil race: 28.5 km - run, 42.5 km – mountains cycling, 17.5 km - kayaking</td>
<td>After exercise: ↑ LDH, ↑ TBARS, ↓ CAT</td>
</tr>
<tr>
<td>Marin et al., 2011 [36]</td>
<td>Handball, n=14, M, 25±4.5 years, TE=11.4±3.1 years</td>
<td>None</td>
<td>Handball match, BC before warm-up, immediately after and 24 h after match</td>
<td>After exercise: ↑ SOD, ↓ CAT, ↓ GPx, ↓ GR, After 24h: ↑ SOD, ↓ CAT, ↑ GPx, ↓ GR</td>
</tr>
<tr>
<td>Mila – Korzeniowska et al., 2013 [35]</td>
<td>Volleyball, n=18, M, 28.3±4 years, TE=11.8±3.2 years</td>
<td>The same study group + exercise</td>
<td>Stage 1: systemic cryostimulation (WBC) and 40 min exercise on ergometer 85% HRmax, 165 W and 50 rev/min Stage 2: exercise on ergometer, 160 W and approx. 50 rev/min BC before and after exercise, + after WBC</td>
<td>Stage 1: after WBC: ↑ SOD, ↑ GPx, ↑ CAT, ↑ TOS After exercise and WBC: ↓ SOD, ↑ GPx, ↓ CAT, ↑ TOS Stage 2: after exercise: ↓ SOD, ↑ GPx, ↓ CAT, ↓ TOS</td>
</tr>
<tr>
<td>Neto et al., 2013 [22]</td>
<td>Volleyball, n=9, M, 17.9±1.1 years</td>
<td>UT, n=9, M, 18.7±1.8 years</td>
<td>3 training phases 3 months before phase 1 and after phases 2 and 3, the following tests were conducted: vertical jump using a free counter movement and bench press, BC in the final week of each stage, 48 h after final exercise training session</td>
<td>Phase 1: ↓ CAT, ↓ GR, ↓ TSG, ↓ RCD, ↓ TBARS Phase 2: ↓ CAT, ↓ TSG, ↓ RCD, ↓ TBARS Phase 3: ↓ CAT, ↓ TSG, ↓ RCD, ↓ TBARS</td>
</tr>
<tr>
<td>Olubajo et al., 2015 [33]</td>
<td>Football, n=12, F, 18.8±1.2 years, TE=2 years</td>
<td>UT, n=10, F, 20.6±0.5 years</td>
<td>Treadmill run, 20 min: Speer increase every 2 min by 0.5km/h up to 1.5km/h, BC before and after exercise</td>
<td>TR after exercise: ↓ SOD, UT after exercise: ↓ SOD, ↓ MDA</td>
</tr>
<tr>
<td>Pesic et al., 2012 [2]</td>
<td>Karate, n=30, M, 20.9±4.1 years, TE=8.7±3.6 years</td>
<td>None</td>
<td>2 x graded maximal test (on cycle ergometer), BC before and after exercise</td>
<td>After training session: ↓ CAT, ↓ O2, ↓ H2O2, ↓ CAT</td>
</tr>
<tr>
<td>Rowlands et al., 2011 [31]</td>
<td>Long-distance runs, n=12 (M), n=3 (F), 37±6.7 years, long TE</td>
<td>None</td>
<td>894 km run, BC before and after run</td>
<td>None</td>
</tr>
<tr>
<td>Shadab et al., 2014 [16]</td>
<td>Hockey, Football, Long-distance runs, n=60, 22.5±4.6 years, TE=1 year, training sessions 4 x week</td>
<td>None</td>
<td>Run 10km/h (90min), BC before and 6h after exercise</td>
<td>After exercise: ↑ MDA</td>
</tr>
<tr>
<td>Trivić et al., 2011, [32]</td>
<td>Wrestling, n=14, M, 21.9±3.5 years, TE=11.7±4 years</td>
<td>None</td>
<td>Aerobic training (75-85% HRmax) 4 weeks, 3 times a week, lasting 60 min each, fasting state BC, day before and after training session</td>
<td>After training session: ↑ SOD, ↑ CAT, ↓ TAC, ↑ GPx, ↓ GR</td>
</tr>
</tbody>
</table>
was played (Table 1). Pesic et al. [2] studied a group of 30 karatekas who performed twice a graded test to exhaustion on a cycle ergometer: 1 - in the first week of the preparatory period (lasting 3 months), 2 - in the first week of the competition. Additionally, a single controlled karate training session was conducted 36 h after the second maximal test. Before and after exercise, and before and after the endurance test, the following indicators of oxidative stress were determined: SOD, CAT, H$_2$O$_2$, O$_2^-$. After the end of the preparatory period, a statistically significant decrease of CAT activity by 16.4% compared to the baseline was observed, while the single karate practice session influenced the statistically significant increase in CAT activity by 28.8%, statistically significant increase in H$_2$O$_2$ concentration of 20.3% and a statistically significant decrease of O$_2^-$ by 25.1% (Table 1). However, in the study by Trivić et al. [32], 14 wrestlers who had completed a 4-week training program took part (3 x a week, 60 min aerobic training at an intensity of 75-85% of maximal heart rate). Blood samples were taken twice in the morning: the day before and the day after the end of the training program. The activity of SOD, CAT, TAS, GPx and GR was marked. After completing the training, the TAS level statistically significantly reduced by approx. 1.5%. It showed an increase in the activity of SOD and CAT, and there were no other changes in the activity of antioxidant enzymes (Table 1).

**The level of oxidative stress in team sports**

Olubajo et al. [33] conducted a study on two groups: a study group comprised of female footballers, a control group of untrained women. The study used a 20-minute graded test on a treadmill consisting of a three-minute warm-up at a speed of 0.5 km/h. Then, the speed of the belt of the treadmill was increased every two minutes from 0.5 km/h to 1.5 km/h. After the exercise, there was a statistically higher level of SOD activity while there was a reduction in CAT activity among the footballers. Additionally, the level of SOD and MDA determined after the exercise test significantly increased in the untrained group (respectively by 33.3% and 39.7%) compared to the value before exercise, and the level of SOD and MDA decreased (by 19.8% and 7.5%) compared to pre-exercise values (Table 1). In other studies on football players, the Wingate test was used [11]. Before and after the test, the levels of TAS, UA and TBIL were determined, the levels of which increased significantly by 4%, 6.5% and 8.3% relative to the resting values (Table 1). In earlier studies, Hammoud et al. [10] also examined a group of football players using the RSA test (Repeated Sprint Ability) on a cycle ergometer (5x 6s maximal sprint + 24 sec rest). The levels of TAS, UA and TBIL were determined at various intervals (morning and evening before and after the exercise test). The morning before the exercise, the level of TAS, UA and TBIL were higher than in the evening of the same day, and in the morning after the exercise, the levels of these indicators increased by 10.7%, 12.2% and 15%. In the evening, the level of TAS, UA and TBIL decreased to the level from before the morning exercise (Table 1) [10]. Shadab et al. [16] examined the level of MDA in football players, hockey players and medium-distance runners before and after 1.5 hours running on a treadmill. MDA levels in these athletes after exercise increased significantly, by more than 6 times (approx. 635.3%) (Table 1). Furthermore de Costa et al. [34] examined a group of 10 footballers who participated in the LIST test (Loughborough Intermittent Shuttle Test), which consisted of walking, sprinting and jogging at an intensity of - 55% VO$_{2\text{max}}$ and the intensity of 95% VO$_{2\text{max}}$. Before, during and after the test, the concentration of urea and MDA was determined. It turned out that the level of MDA significantly increased by 24.8% (Table 1) while the resting values of AOPP, MDA, TAS were marked by Hadžović - Džuvo et al. [17] in the study group consisting of football players, basketball players and wrestlers. The results were compared between the groups of athletes. It was shown that a significant statistical difference was only in the level of MDA of basketball players - considerably higher (80.4%), in comparison to the footballers (Table 1). Gokhan [12], in his study, compared the results of indicators of oxidative stress marked during resting of the volleyball and untrained young men. The level of TAS, TOS and OSI was significantly higher in volleyball players than in the control group, which may be the result of the conducted training (Table 1). However, Bulduk et al. [20] conducted a 20-m zig-zag run test in groups comprising of volleyball players and untrained women, and determined MDA, GSH and CAT. They found that the concentration of GSH and CAT assay in both groups significantly decreased by 26% and 13%, while the level of MDA significantly increased by 31.5% in the volleyball group, and 14.5% in the control group (Table 1). Neto et al. [22] in turn, studied volleyballers, introducing a 3-phase training program lasting three months, which corresponded to the periods of training of elite volleyball players (phase 1 - exercises of low intensity for 5 weeks; phase 2 - exercise of increased intensity and at the beginning of the championship for 5 weeks; phase 3 - exercise with reduced load and during the finals of the championship for 3 weeks). They compared the concentration of CAT, RCD, TBARS, GR levels of the study and control groups, at various stages of preparation for the championship. The concentrations of GR in the study during phases 1 and 2 were significantly higher than in the control group, and in phase 3, they were significantly higher relative to the control group and phase 2. Statistically significant changes in
the level of CAT can be seen in the third phase of exercise when compared to the control group. The concentration of RCD in the study group was reduced in phase 2, both with respect to phase 1 and the control group. In phase 3, in both study and control groups, comparatively higher levels of RCD were reported. There were no differences in the levels of TBARS between groups and in different phases. On the basis of these results, it can be stated that the volleyball players presented the lowest level of oxidative stress in combination with the best indicators of the possibility of exercise in the fundamental phase - phase 3 (Table 1). Other studies included comparison of the effect of a single cryostimulation session and exercise on the ergometer on the activity of antioxidant enzymes and TOS in volleyball players. The test results showed no statistical difference in the activities of GPx, SOD and TOS, while the CAT activity after the same exercise increased significantly by 100%, and for cryostimulation and exercises, they were approx. 2 times lower than in the case of the same exercise on the ergometer (Table 1) [35]. The level of reactive oxygen and nitrogen species resulting from the exercise leading to a significant level of muscle damage may persist for up to several days, in contrast to the low-level exercise causing muscle damage resulting in normalized ROS, occurring for only a few hours. Marin et al. [36] examined 14 handball players before, immediately after and 24 hours after the match was played. Determined were: TBARS, TAS, GSH, GSSG, GSH/GSSG, SOD, GPx, GR and CAT. It was found that a single game of handball leads to oxidative stress. Found were: a statistically significant decrease in GSH concentration of approx. 18% immediately after the match, a statistically significant increase SOD activity after the match by 166% compared to the resting value and 248% after 24 hours of rest, and a statistically significant decrease in the activity of CAT and GR immediately after the match by 36% and 46%, and 24 hours after the match by 57% and 53%. In addition, handball players’ plasma showed a statistically significant increase in TBARS concentration immediately after the end of the match by 62%, and this upward trend persisted for 24 h after the end of the match (up to about 153%) (Table 1). Other researchers, in turn, researched handball players and people leading a sedentary lifestyle. Blood was collected before and after the exercise test on a cycle ergometer until exhaustive. The results showed [19] a statistically significant reduction of CAT activity in the group of people training handball (Table 1). In contrast, a study involving athletes of various disciplines was conducted by Conti et al. [37]. Their aim was to compare the response of the antioxidant system as indices of oxidative stress in the blood serum of athletes. The study consisted of athletes from disciplines of a different nature: aerobic-anaerobic - 10 triathletes, aerobic - 15 footballers and anaerobic - 10 sprinters. Venous blood was collected from the subjects once, during fasting, and the following were determined: CAT activity, TBARS and NO in blood serum. TBARS concentration differed significantly between the groups. The level of lipid peroxidation was significantly higher among football players compared with triathlon athletes and sprinters. CAT activity was significantly higher in the footballs players compared to other players and statistically higher in sprinters than triathletes (Table 1) [37].

Summary

Free radicals are highly reactive. They are synthesized in the body under physiological conditions. Depending on the concentration, they can have positive or negative effects on the body. In accordance with the principle of hormesis, increases in ROS production are a positive incentive for the regulation of the formation of endogenous antioxidant defense of the organism [38]. As follows from this study, regular physical activity is associated with the adaptation of the body in response to oxidative stress. Because regular exercise increases the antioxidant defense mechanisms in the skeletal muscle by activating both the gene expression of SOD and glutathione peroxidase, thereby increasing the effect of the body’s defense against the harmful effects of ROS [7]. The results of studies confirm that intense exercise can cause intensification of ROS production, and thus lead to oxidative stress. Depending on the type of exercise, a variety of oxidation products can be produced in different amounts. Thus, increasing physical fitness proves to be an effective way to improve the antioxidant defense system, and therefore, to stay healthy. However, it should be noted that the degree of redox homeostasis disorders caused by exercise depends on many factors, including the type, intensity and duration of the exercise, the exerciser’s state, gender and age.

References:


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