REGULATIONS FOR ARTICLE PUBLICATION

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.

Editorial office: Antropomotoryka
Al. Jana Pawła II 78, 31-571 Kraków. Poland.
E-mail: antropomotoryka@awf.krakow.pl

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 (anthropomotorsics) 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).

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., Objasnienia, 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/vancouv.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:

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:**

<table>
<thead>
<tr>
<th>Group</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.

**Regulations for reviewing:**

- Articles submitted for publication by the IC Publishers Panel are reviewed by at least two independent reviewers. The names of the reviewers are not revealed. Authors and reviewers do not know each other’s identity (double-blind review process).
- The publisher reveals a list of reviewers to the public once a year, in the last issue of the quarterly journal.
- Reviews are performed using the IC Publisher Panel review worksheet. **Reviewers are required to formulate a clear conclusion regarding approval or rejection of an article for publication.**
- Reviewing procedures should be in accordance with the guidelines of the Ministry of Science and Higher Education of Poland, which may be found on the following websites:
  - Subcription 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 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/

**Concluding remarks**

- Articles not prepared in accordance with the requirements of the “Article publication requirements” will be returned to the author for improvement. The publisher reserves the right to remove linguistic defects or apply abbreviations.
- The publisher reserves the right to adjust or condense the text, make improvements related to terminology standardization.
- 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.

**Table 1. Differences (d) in body height and mass as well as BMI between student group A and B**

<table>
<thead>
<tr>
<th>Group Variable</th>
<th>A</th>
<th>B</th>
<th>d</th>
<th>Significance level p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>21.5</td>
<td>3.2</td>
<td>22.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Body height [cm]</td>
<td>176.2</td>
<td>3.3</td>
<td>178.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Body mass [kg]</td>
<td>68.3</td>
<td>2.7</td>
<td>79.4</td>
<td>3.5</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>22.3</td>
<td>2.2</td>
<td>25.7</td>
<td>2.8</td>
</tr>
</tbody>
</table>

**NS** – statistically non-significant difference

* – p<0.05; ** p<0.01; ***p<0.001

Example:


**Veracity in Scientific Research and Respect for Intellectual Property:**

http://bbn.uksw.edu.pl/node/76

**Ethical Principles of a Scientific Researcher:**


**Regulations regarding eligibility for printing:**

- Articles to be moved to the next issue.
- Delay in re-submission/consent may cause the article to be moved to the next issue.

Example:

CONTENTS

EDITOR-IN-CHIEF’S FOREWORD
Edward Mleczko

Antropomotoryka. Journal of Kinesiology and Exercise Sciences, issue No. 70: Identification of talent and conditions for its development in competitive sports ........................................................................................................................... 9

SECTION – SPORT SCIENCES
Issurin Vladimir
Early precursors of athletic talent: evidence from a study among Olympic Champions ........................................... 11

Marcin Starzak, Hubert Makaruk, Jerzy Sadowski
Step length adjustment in the long jump with and without take-off board in non-long jumpers ........................................... 17

Krzysztof Kusy, Ewa Zarębska, Monika Ciekot-Sołtysiak, Michał Janowski, Jacek Zieliński
Cardiorespiratory response and energy system contribution during speed endurance workout in a highly trained sprinter: a preliminary report ........................................................................................................................... 25

SECTION – FUNDAMENTAL AND APPLIED KINESIOLOGY
Krzysztof Krawczyk
Selected parameters of anaerobic capacity and body tissue components in handball players from the premier league team .............................................................................................................................................................. 35

Barbara Koperska, Bartosz Trybulec
The influence of two-person officiating on the range of movement of the cervical spine in basketball referees ............... 41

Natalia Radlińska, Arkadiusz Berwecki
The assessment of range of motion in selected joints in competitive swimmers ........................................................... 51

Bartłomiej Ptaszek, Aneta Teległów, Jacek Głodzik, Jakub Marchewka
Impact of systemic cryotherapy on selected enzymes, glutathione and serum total protein levels in healthy young males 61
In each of its seven articles, this issue of *Antropomotoryka Journal of Kinesiology and Exercise Sciences* (JKES) – the seventy one already – a joint effort of Krakow’s and Wroclaw’s academics, has both Polish and foreign authors approach the problem of identifying talent and developing it in competitive sports. What draws attention to them is not only the originality of the subject of research – that is, top class athletes – but, above all, the quality and innovativeness of applied tools and methods.

The above-mentioned merits may be seen in the results of research published in one of the articles, authored by a well-known Israeli scientist from the famous Orde Wingate Institute for Physical Education and Sport, located south of the city of Netanya, Israel. In the article “Earlier Precursors of athletic talent: evidence from a study on Olympic champions”, the professor managed to obtain information using original techniques of diagnostic survey from eleven Olympic medallists of various disciplines, as well as their coaches and managers, on the psychic and training determinants of their initial successes in competitive sports. The former assumption of psychologists [Ericson et al., 1993], suggesting the need for 10,000 hours of training over a time span of 10 years for achieving international success was verified. Undoubtedly, these findings must lead to reflection on the quality and intensity of the training that the younger candidates for Olympic champions are already doing.

The information contained in the article “Step length adjustment in the long jump with and without take-off board in non-long jumpers” is definitely of great importance for trainers of athletics. With the use of high-end measuring equipment, it was proved based on results of 14 men and 6 women practicing the long jump at the master level that in order to achieve maximum acceleration, and particularly the highest power at the bounce spot, starting blocks should be put aside during training.

In terms of cognitive approach, the results of the case study “Cardiorespiratory response to speed endurance workout in a highly trained sprinter” are very important. The study contained the results of a continuous study of Polish sprinters reaching the level of international mastery. So far, special attention was paid to research on the physiology of long distance runners. The conducted observations show that it is possible to include the volatility control of physiological indicators of aerobic and anaerobic capacity in the training programme of sprinters.

Other studies show that the existing methods of shaping endurance capacity of Polish handball players playing in the super league ought to be changed. The authors of the article “Selected parameters of anaerobic capacity and body tissue components of super league handball players” believe that in training handball at a high level, attention should be focused on shaping training according to endurance intervals based on anaerobic processes.

There is little research dealing with both positive and adverse effects on physical fitness of the load applied by referees during matches. On the basis of the research results presented in the article “The influence of two-per-
son officiating on the range of movement of the cervical spine in basketball referees”, it can be surmised that the range of motion of their cervical spine is changing dramatically. When examining 31 basketball referees, it was concluded that before the match, the average range of the passive bend was 5.70 cm for the left bend and 5.13 cm for the right bend (p < 0.05). The average range of the active bend was also significantly greater in the case of the right bend and equalled 5.16 cm (as opposed to the left bend, which equalled 4.66 cm at p < 0.05). The average active range of body extension before the match equalled 7.33 cm and 6.89 cm Decreased it after the match (p < 0.05). The average range of the left head turn before and after the match was 8.74 cm and 8.20 cm, respectively (p < 0.05). Noteworthy is the inversely proportional relationship between the seniority of a referee and the reported joint mobility of their cervical spine.

In the article “Impact of Systemic Cryotherapy on selected enzymes, glutathione and serum total protein levels in healthy young males”, the team of researchers from Krakow referred to the very popular method of physiotherapeutic treatment of various diseases and sports injuries, that is cryotherapy (WBC – Whole Body Cryotherapy). It is a known fact that cryotherapy, whose name comes from the Greek word kryos (frost), began to be distinguished and regarded as a scientific method only in the 1970s thanks to a Japanese professor Toshiro Yamauchi, the promoter of the use of low-temperature chambers and portable cryo-applicators. Although the healing properties of the cold have been already known 2500 years before Christ – its advantages were described by the father of medicine, Hippocrates at the turn of the 4th/3rd century B.C. – it is only since the 1980s that the stimulating properties of extremely low temperatures have been included in the scope of scientific consideration. Experiments and observations are continuously carried out to establish contraindications to use cryotherapy and to improve the methods of physiotherapy. The authors of the recommended work have been dealing with the problem for a number of years. The results of their research partially confirmed the effectiveness of a series of ten daily cryotherapy treatments, in which short-lasting, stimulus-like use of cryogenic temperatures (below –100°C) was used to improve the rheological blood indicators.

I hope that this brief overview of the contents of this issue of Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) encourages the reader to pursue the valuable research results published here. It is worth noting that competent, critical and objective reviewers had the same opinion about the professionalism of the texts and the possibilities of transferring the research results to competitive sports practice. I would like to express my gratitude for their selfless help with the editing of the journal. I believe that the next, similarly professional issue of our journal will reach the readers swiftly.

Edward Mleczko
Editor-in-chief
EARLY PRECURSORS OF ATHLETIC TALENT: EVIDENCE FROM A STUDY AMONG OLYMPIC CHAMPIONS

Issurin Vladimir

Wingate Institute for Physical Education and Sport, Netanya, Israel

Key words: athletic talent, retrospection analysis, long-term preparation, talent precursors

Abstract

The aim. To define sport mastery psychic determinants and its training conditions at the early stage of the sport training
Hypothesis. The duration of time that was assumed by psychologists to bring first sport results: 10 years 10 000 hours of the training volume [1] was verified.
Subject of the study. 11 Olympic champions (various sports disciplines), coaches and sport managers.
Methods. The diagnostic poll method using interview techniques, polls and documents analysis.
Results.
– before committing to their sport profession they used to anticipate in various sport disciplines. Only professional swimmers tended to start their career at childhood, others tended to commit to their professions when at puberty.
– they required less time to achieve their first international results than it was presented in the theoretical assumptions at the time.
– they owned the typical psychic features for their professional sport discipline. The most common mentioned were: Self-motivation, high responsibility, fatigue tolerance, physique, emotional stability, fast learning skills, competitiveness, mental toughness,
Conclusions. 1. The beginning of the swimming career was confirmed to be at childhood and youngsters at puberty.
2. Contrary to the theoretical assumptions the Olympic champions required less time to achieve first international sport successful results
3. All gathered evidence provided the foundation to undermine psychologists’ assumptions [1] regarding the time required to bring young athlete first successful results in sport 4. The work volume required to achieve first international successes by the Olympic champions on avarage took = 3084 hrs (min 1840 hrs– max 4495 hrs).

Introduction

Identification and promotion of athletic talent is one of the most disputable and important problems of contemporary sports science. Sports history of great Olympic athletes can give valuable input into investigation of the nature and discovery of athletic talent. The interest to personalities, athletic biographies and particularities of long-term preparation of great champions was tradi-
traits and some psychological skills, which predetermine their successful athletic careers. Apparently, such an appropriate, in-depth study of outstanding athletes can give relevant information related to the availability of early precursors of their athletic talent.

**Purpose**

The study purpose is to investigate and deal with the investigation of long-term preparation of outstanding athletes aiming to find early precursors of their athletic talent.

**Material and methods.**

The study design presupposed in-depth interviewing of eleven Olympic champions, representing different countries. In addition, several personal coaches and sport managers were questioned as well. Retrospective data of the subjects were collected with regard to their sport history, namely; premature athletic activity before preparation in their favorite sport, age at which systematic training of this favorite sport started and age at which they achieved their first big success; total accumulated training time expenses each year prior to the first big success; personality traits and psychological characteristics identified during initial stages of long-term preparation; availability of early indications of extraordinary athletic abilities. All subjects were informed of the study purpose and expressed their readiness for cooperation.

**Results**

**Training specifics of outstanding athletes at the initial stage of long-term preparation**

The available data give objective information concerning content, workout frequencies, time expenses for training per week and over the season during the stage of preliminary preparation of the surveyed outstanding athletes (Table 1).

As it is shown in Table 1, all subject executed much higher training volumes during the initial stage of their care erthan the generally recommended norms and standards. Moreover, their training volumes largely exceed the workloads performed by their peers. According to self-reports of the surveyed athletes, they executed increased workloads following their self-motivation within-

<table>
<thead>
<tr>
<th>Athlete’s name</th>
<th>Age of preliminary preparation</th>
<th>No. of workouts per week</th>
<th>Training time expenses per week, Hrs</th>
<th>Total training time per year, Hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viatcheslav Ivanov (VI) – rowing; USSR</td>
<td>14–15</td>
<td>5–9</td>
<td>9–16</td>
<td>580–620</td>
</tr>
<tr>
<td>Yuri Stetsenko (YS) – kayaking; USSR</td>
<td>14–15</td>
<td>3–4</td>
<td>6–8</td>
<td>200–450</td>
</tr>
<tr>
<td>Sergey Chukhray (SC) – kayaking; USSR</td>
<td>13–14</td>
<td>8–10</td>
<td>10–14</td>
<td>480–560</td>
</tr>
<tr>
<td>Vladimir Parfenovich (VP) – kayaking; USSR</td>
<td>14–15</td>
<td>5–7</td>
<td>8–12</td>
<td>350–410</td>
</tr>
<tr>
<td>Ivan Klementiev (IK) – canoeing; USSR, Latvia</td>
<td>15–16</td>
<td>6–8</td>
<td>10–16</td>
<td>380–540</td>
</tr>
<tr>
<td>Maxim Opalev (MO) – canoeing; Russia</td>
<td>12–13</td>
<td>8–11</td>
<td>10–15</td>
<td>230–310</td>
</tr>
<tr>
<td>Gal Fridman (GF) – windsurfing; Israel</td>
<td>12–13</td>
<td>6–8</td>
<td>9–12</td>
<td>600–650</td>
</tr>
<tr>
<td>Massimiliano Rosolino (MR) – swimming; Italy</td>
<td>9–10</td>
<td>4–6</td>
<td>7–10</td>
<td>180–290</td>
</tr>
<tr>
<td>Sergey Fedorovtsev (SF) – rowing; Russia</td>
<td>13–14</td>
<td>4–6</td>
<td>6–12</td>
<td>350–560</td>
</tr>
<tr>
<td>Ruta Meilutyte (RM) – swimming; Lithuania</td>
<td>7–8</td>
<td>4–5</td>
<td>4–6</td>
<td>280–420</td>
</tr>
<tr>
<td>Daria Domracheva (DD) – biathlon; Belorussia</td>
<td>12–13</td>
<td>6</td>
<td>14–16</td>
<td>460–520</td>
</tr>
<tr>
<td>Average internationally accepted standard</td>
<td>Duration – 2–3 years</td>
<td>3–4</td>
<td>3–5</td>
<td>120–170</td>
</tr>
</tbody>
</table>
out external pressure or any additional demands. These additional extra work load sconsisted of voluminous low intensity exercises with accentuated technical control. Importantly, the coaches of the studied athletes always supported their initiative in execution of additional tasks and sessions and were attentive to technical details of performance but gave sufficient freedom in execution of additional tasks and sessions. In addition, all subjects remarked that they felt satisfaction from their training activities.

**Premature sport activities and choice of the favorite sport**

The findings evidenced that a majority of studied athletes practiced some other sport activities before they started systematic preparation in their favorite sport. Some of them have had preparation in organized groups, namely: VI became qualified boxer before he started training in rowing, VP had 5 years training practice in wrestling, DD trained cross-country skiing for 6 years. The other subjects (YS, SC, IK and SF) practiced different sports such as football, running, skiing, etc. in informal activities. Several athletes who began their dedicated preparation at an early age started it in favorite sport, namely, RM and MR in swimming, MO in canoeing/kayaking and GF in windsurfing.

**Total accumulated training time expenses before 1st big success**

The total training time duration since the beginning of purposeful preparation until the 1st big success varied between 4 and 7 years. The 1st big success as an indicator of expert performance has been specified as earning a medal at World/Continental Junior Championships or National Senior Championships [3, 4]. The average accumulated training time expenses until the first big success was equal to 3,084 hours that varied between 1,840 and 4,495. Although the studied athletes executed much larger volumes of training compared to their peers and the workload standards, their total accumulated training time was much less than proposed by Ericsson et al. [1], who postulated the 10-year rule and 10,000 hours of deliberate practice until attainment of a superior level of expert performance.

**Early signs of sport-specific giftedness**

Information on early indicators of extraordinary athletic abilities was received immediately from the subjects as well as from their coaches and sport managers. The questioned persons marked various signs of giftedness emphasizing psychological attributes, physical features such as learn ability, fatigue tolerance and body build (Table 2).

<table>
<thead>
<tr>
<th>Athlete’s name</th>
<th>Age starting training in favorite sport</th>
<th>Age when EI were marked</th>
<th>Indicators of extraordinary athletic abilities*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viatcheslav Ivanov (VI)</td>
<td>14</td>
<td>15–16</td>
<td>Self-motivation, consciousness, fatigue tolerance, body build, learn ability, competitiveness</td>
</tr>
<tr>
<td>Yuri Stetsenko (YS)</td>
<td>14</td>
<td>15–16</td>
<td>Self-motivation, high responsibility, competitiveness, learn ability, self-esteem, fatigue tolerance</td>
</tr>
<tr>
<td>Sergey Chukhray (SC)</td>
<td>13</td>
<td>14–15</td>
<td>Self-motivation, mental toughness, fatigue tolerance, learn ability, body build</td>
</tr>
<tr>
<td>Vladimir Parfenovich (VP)</td>
<td>14</td>
<td>15–16</td>
<td>Self-esteem, self-motivation, competitiveness, , body build, fatigue tolerance, emotional stability,</td>
</tr>
<tr>
<td>Ivan Klementiev (IK)</td>
<td>15</td>
<td>18</td>
<td>Self-motivation, dedication, learn ability, fatigue tolerance, emotional stability, competitiveness.</td>
</tr>
<tr>
<td>Maxim Opalev (MO)</td>
<td>12</td>
<td>13</td>
<td>Self-motivation, competitiveness, high responsibility, dedication, learn ability, fatigue tolerance</td>
</tr>
<tr>
<td>Gal Fridman (GF)</td>
<td>12</td>
<td>12–14</td>
<td>Self-motivation, high responsibility, fatigue tolerance, learn ability, emotional stability, competitiveness</td>
</tr>
<tr>
<td>Massimiliano Rosolino (MR)</td>
<td>6</td>
<td>9</td>
<td>Self-motivation, learn ability, awareness , body build, competitiveness</td>
</tr>
<tr>
<td>Sergey Fedorovtsev (SF)</td>
<td>13</td>
<td>15</td>
<td>Self-motivation, high responsibility, fatigue tolerance, body build, learn ability</td>
</tr>
<tr>
<td>RutaMeilutyte (RM)</td>
<td>7</td>
<td>9</td>
<td>Self-motivation, high responsibility, consciousness, dedication, learn ability, body build</td>
</tr>
<tr>
<td>Daria Domracheva (DD)</td>
<td>12</td>
<td>13–14</td>
<td>Self-motivation, high responsibility, fatigue tolerance, competitiveness, mental toughness, learn ability</td>
</tr>
</tbody>
</table>

* Indicators are ordered according their importance as declared by athletes and/or their coaches
As it can be deduced from the data in Table 2, self-motivation was highest ranked by the subjects. Among the other personality traits indicated by the questioned athletes were competitiveness, high responsibility, consciousness and dedication. Several athletes mentioned psychological skills such as mental toughness and emotional stability. The most influential physical attributes mentioned by the subjects appeared to be high learn ability and fatigue tolerance.

**Discussion**

One of the most salient outcomes of the present study is the fact that all the outstanding athletes who were interviewed executed much larger volumes of training at the initial stages of their long-term preparation. The athletes increased the level of the workload following their own self-initiative without any external demands. They also reported that they felt satisfaction from training routines and athletic progression. Importantly, each of them marked self-motivation as one of the decisive factors determining their successful preparation. These findings are consistent with the data of Gould et al. [5] who interviewed 10 US Olympic champions and revealed that motivation of achievement competence was indicated by each subject as an important reason for sport activity during their early years. The summary of many studies allowed to find that self-motivation is definitely one of the most frequently mentioned features of the potentially talented youth (see review by Anshel and Lidor [8]). However, in order to be intrinsically motivated, the athlete should feel that his/her efforts lead to visible enhancement of skills and sport-specific abilities, and this positive feedback produces strong support for continued preparation. It is apparent that perceived competence plays a crucial role in maintenance and rein for cement of an athlete’s self-motivation [9].

Contrary to the theory by Ericsson et al. [1], all subjects marked and emphasized that their initial training activities were always enjoyable. The excellent swimmer Massimiliano Rosolino reported that he feels satisfaction from training and loves it very much. Similarly, the following three Olympic champions – Viatcheslav Ivanov, Sergey Chukhray and Vladimir Parfenovich noticed that they experienced satisfaction from training from the first steps in their athletic careers. Apart from that, Ericsson’s theory [1] is refuted with regard to the amount of deliberate practice. In all cases, the total amount of training time expenses until achievement of a level of expert performance (1st big success) was much less than 10,000 hours. Eventually, exceptionally talented athletes attain a level of excellence much faster than proposed in the theory by Ericsson, whereas the less talented individuals do not achieve this level even after 10,000 hours of highly dedicated practice.

**Conclusions**

Unlike the traditional approach mostly functioning along with somatic and physiological prerequisites of athletic talent, the findings of this study emphasize the importance of behavioural and personality traits, which can serve as early predictors of athletic talent. The most important precursor of athletic talent in the great athletes studied was their willingness and readiness to perform much larger workloads compared to their peers and team mates. The introduced findings are evidence that such personality traits as self-motivation, competitiveness, high responsibility, consciousness and dedication have a high predictive potential for athletic talent. In addition to these, the gifted performers have shown early acquisition of psychological skills such as mental toughness and emotional stability. The most influential physical attributes mentioned by the subjects appeared to be high learn ability and fatigue tolerance.

The available data contradict the theory of deliberate practice by Ericsson et al. [1] that proposes the 10-year rule and accumulation of 10,000 hours of highly dedicated practice for achieving a level of expert performance. The greatly talented athletes studied obtained the level of excellence following 4-7 years of specialized preparation with the average accumulated training time expenses equaling 3,084 hours. The reported particularities of superior athletes and their preparation during the initial stage of their careers in sport can be used for the early identification of potentially talented young prospects.

**References**


Early precursors of athletic talent: evidence from a study among Olympic Champions


Address for correspondence:
Vladimir Issurin
vladi2691@gmail.com
STEP LENGTH ADJUSTMENT IN THE LONG JUMP WITH AND WITHOUT TAKE-OFF BOARD IN NON-LONG JUMPERS

Marcin Starzak\textsuperscript{ABCDGF}, Hubert Makaruk\textsuperscript{ABCEG}, Jerzy Sadowski\textsuperscript{AG}

Department of Athletics, The Josef Pilsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport, Biala Podlaska, Poland

Key words: athletics, step pattern, variability, task complexity

Summary

Introduction. Research has shown that step length adjustment determines long and triple jump performance. Aim. To identify differences in step length adjustment between long jump conditions with (TB) and without (NTB) take-off board.

Material and methods. Fourteen male (mean age 22.4 years, ± 0.6, body height 182.6, ± 5.8 cm, and mass 77.5, ± 6.3 kg) and six female (mean age 22.1 years, ± 0.4, body height 164.6, ± 2.8 cm, and mass 58.4, ± 6.1 kg) non-long jumpers participated in this study. The subjects performed 6 long jump trials under each condition. The final 10 steps were used for analysis. The Optojump Next device was used to evaluate the kinematic parameters. The step length adjustment was determined by variability of footfall position during the approach run.

Results. Significant (p < 0.05) differences of variability in footfall position during the approach run between two conditions were found. In addition, the percentage distribution of step length adjustment was different during the penultimate and last steps under all conditions.

Conclusions. The results of the research indicated that to achieve better foot placement during the take-off, the long jump should be performed from the take-off board. The coaches should implement long jumps without the take-off board into training routines to improve step pattern consistency and lengthen an athlete’s particular steps during the approach phase.

Introduction

One of the main determinants of successful performance in the long and triple jump is proper execution of the approach run. The crucial requirements throughout this phase are foot accuracy during the take-off, near maximal horizontal velocity of the athlete’s center of gravity and optimal body position that generates vertical velocity from the board [1]. It was found that when approaching the board, jumpers maintain sprinting actions until the last two to three steps before reaching the take-off board [2]. A typical action over this last stage of the approach run is the last step slightly shorter than the last-but-one step before the take-off [3]. These step adjustments lead to a small increase in horizontal velocity and lowering of a jumper’s center of gravity. Placing the take-off foot precisely close to the edge of the take-off board maximizes effective distance of the jump and hence, body transition from run-up to the take-off. Therefore, precise foot placement during the approach run is required because athletes cannot reproduce an identical step pattern from the starting mark to the end of the run-up [4]. Each change in step placement in the final phase of the approach run may also lead to negative
influence on crucial take-off kinematic parameters that are significantly connected with the performance of the jump [2, 3].

Lee et al. [5] showed that the approach phase consists of two sub-phases. In the first phase (acceleration phase), an athlete produces a constant stride pattern, systematically increasing speed to achieve an appropriate run rhythm while maintaining proper alignment of the body. In the second phase (zeroing-in phase), athletes modify their step length parameters over the final steps [1]. This is revealed as an increasing trend in variability of footfall placement followed by a decreasing trend for the final steps before reaching the take-off board [6].

It is considered that visual regulation of step length plays a significant role in take-off accuracy [5]. Optic flow ‘tau’, which provides information on time-to-contact with the take-off board, is responsible for that regulation [5, 7]. Montagne et al. [8] suggested that control mechanism is based on perception-action coupling in the run-up phase which operates continuously and is not connected with the particular step, so adjustments are performed only when necessary.

The step length adjustment was previously observed in both the long jump [1, 9] and triple jump [1, 10–11]. This regulation usually begins during the final 4–5 steps before take-off for expert jumpers [1, 5, 6, 9]. However, a similar pattern of adjustment has been demonstrated at a different skill level in non-expert and novice long jumpers [9, 12–15] regardless of their gender [1, 6]. It was also shown that an earlier onset as well as duration of visual control have a positive effect on long jump performance [12].

In relation to the above-mentioned findings, regulation of step length adjustment (decrease in footfall variability) occurs only when the jumper moves towards the take-off board. In the situation that we move in an unobstructed straight line (sprinting), this regulation does not occur and variability of step placement consistently increases [4, 16]. These differences in variability of footfall placement suggest that a jumper’s step might also be controlled in a different manner depending on the task. In the long jump, the main aim is to jump as far as possible. This forces a jumper to maximize precision of foot placement to hit the take-off board perfectly. Previous researchers showed that the task nested at the end of the run-up phase has influence on step regulation [17]. It was observed that when performing approach runs in different task conditions, jumpers use different strategies of step length adjustment [12, 18]. Athletes adjust the step length later when performing the long jump in comparison to run-throughs, a special, commonly used technical exercise. The earlier initiation of step adjustments were also seen as an interaction between jumpers and environmental conditions [19]. In the long jump without the take-off board, also widely applied in training routines, the jumper tries to reach maximum horizontal speed with no limitations related to the take-off at the end of the approach run. It seems that performing the long jump under this condition could result in specific regulation of the steps. These differences in step length adjustment and step characteristics between the long jump with and without the take-off board have not been established so far.

The purpose of this study was to identify step length regulation during the approach run in the long jump with and without the take-off board of non-long jumpers by evaluating the step characteristics throughout the final phase of the approach run.

**Material and methods**

**Subjects**

Fourteen male (mean age 22.4 years, ± 0.6, body height 1.83 ± 0.06 m, and mass 77.5 ± 6.3 kg) and six female (mean age 22.1 years, ± 0.4, body height 1.64, ± 0.03 m, and mass 58.4, ± 6.1 kg) healthy and injury-free non-long jumpers participated in this study. They were untrained physical education students who completed the long jump course at the University of Biała Podlaska. The criteria for inclusion into this study were as follows: at least a ‘good’ grade (4) in the long jump course and six valid jumps under both of the analyzed conditions. This experiment was approved by the University Ethics Committee and all participants read and signed informed consent.

**Procedure**

The subjects performed 6 long jump trials under two different conditions, during two separate jumping sessions with a one-week break between them. The first condition was a long jump with the take-off board (TB) placed at a standard 2 meter position from the sandpit. Under the second condition, the subjects performed a long jump without the take-off board (NTB) on the runway path. To avoid potential order effects, two performance sequences were used with randomized counterbalanced order: TB-NTB, NTB-TB. Each jumping session started at 11 am. Before the beginning of both sessions, the subjects performed a 10-minute dynamic warm-up. The resting period between each jump was 6–8 minutes. All the participants were asked to jump as far as possible and were not penalized for foul jumps. All jumps were measured from the toe of the jumping foot to the nearest trace in the sandpit. The total length of the performed approach runs was individual and consisted of 14 to 16 steps.

**Data collection**

The study was performed at the athletics hall with a tartan surface. All the trials for every subject totaling 240 were registered and analyzed. The final 10 steps...
(11 support phases) were used for analysis. The Opto-jump Next (Microgate, Italy) measurement system was used in this study. This device consists of two pairs of 1-meter long measurement bars, placed parallel to each other and connected to a computer via a USB port. The measurement bars transmit a solid infrared light beam to each other at a height of 2 mm above the floor. For the purpose of this investigation, twenty-five bars (a 25-meter path) were used, placed outside the lines along the approach in a distance of 4 m between them. This device provides accurate information on step length and foot placement during the approach run [20].

Data reduction

Unlike the previous studies [see e.g. 1, 5, 9], the position of the foot during the approach run was calculated by Optojump Next. The step length adjustment was determined by variability of footfall position during the approach run. To determine variability of foot placement for each subject, the standard deviation (SD) of mean toe-to-reference point distance across trials was calculated. The horizontal distance between the toes of every analyzed support foot and the front edge of the take-off board was taken for TB conditions. Under NTB conditions, the distance between each toe of the supporting foot and the reference point located at the front edge of the sandpit was used. The maximum mean SD of toe-to-board distance and toe-to-reference point distance in each condition was considered as a starting point for step length adjustment.

The percentage distribution of step length adjustment (ADJ %) over the final steps was calculated using the formula proposed by Hay [6]:

\[
ADJ_i = \left( \frac{SD_{i} - SD_{i-1}}{SD_{\text{max}} - SD_{i}} \right) \times 100\%
\]

where, \(SD\) is the standard deviation of toe-to-board distance or toe-to-reference point, \(i\) is \(i\)th-last step (support phase), \(SD_{\text{max}}\) is maximal standard deviation of toe-to-board distance, \(SD_{i}\) is standard deviation of toe-to-board distance during the take-off.

This formula determines the percentage proportion of adjustment in each of the final steps to total adjustments made by the subject.

Data analysis

Before statistical analysis was conducted, all data were tested for normality and homogeneity of variance. A general linear model with repeated measures was used to examine the difference between the following factors: conditions x steps. Statistically significant results were further analyzed with Fisher’s post-hoc LSD test. The Student’s t-test was used for statistical comparison between the distances jumped under both conditions. The level of significance for all measurements was accepted at \(p < 0.05\). Statistica 10.0 PL and Microsoft Excel 2010 software were used for all statistical calculations.

Results

Step length adjustment

Figure 1 demonstrates variability of footfall placement during the last 10 steps (11 support phases) of the approach run in the long jump with and without the take-off board. The analysis revealed significant effects

![Fig. 1. Variability of footfall placement throughout the last 11 support phases of the approach run under two conditions. TB – long jump with take-off board, NTB – long jump without take-off board, TO – take-off. * – Significant difference (\(p < 0.05\)), # – Significant difference (\(p < 0.01\))](image-url)
of the step \((F_{10,190} = 37.46; p < 0.01)\). The significant step x condition interaction \((F_{2,38} = 8.21; p < 0.01)\) was found. The effect of the conditions was not significant \((F_{1,19} = 3.02; p > 0.05)\). It was observed that the variability in footfall placement under NTB conditions was significantly \((p < 0.05)\) lower than TB conditions during the first analyzed step until the second-to-penultimate step, except for step 10 and 1 from the take-off board.

**Percentage distribution of step length**

Figure 2 shows percentage distribution of step length during the last 3 steps of the approach run in the long jump with and without the take-off board. The results of analysis revealed significant step x condition interaction \((F_{2,38} = 7.95; p < 0.01)\). There were no significant main effects for the step \((F_{2,38} = 0.55; p > 0.05)\) and conditions \((F_{2,38} = 0.04; p > 0.05)\). Post-hoc analysis showed that percentage distribution was lower under TB conditions during the last step, and higher in TB conditions during the penultimate step.

**Step length characteristics**

Figure 3 presents the lengths of particular steps in the long jump with and without the take-off board. The results of analysis showed a significant effect for the step \((F_{9,171} = 29.61; p < 0.01)\) and conditions \((F_{1,19} =\)

![Fig. 2. Percentage distribution of step length adjustment over the last three steps of the approach run under two conditions. TB – long jump with take-off board, NTB – long jump without take-off board, L – last step. * – Significant difference (p < 0.05)](image1)

![Fig. 3. Differences between step lengths in the approach run under two conditions. TB – long jump with take-off board, NTB – long jump without take-off board, L – last. * – Significant difference (p < 0.05), # – Significant difference (p < 0.01)](image2)
12.28; p < 0.01). In addition, the step x condition interaction was also significant (F(5,71) = 3.44; p < 0.01). Under NTB conditions, step lengths were longer compared to TB conditions.

**Distance jumped**

The mean distance of all jumps under the TB condition was 5.01 m (SD = 0.49) and under NTB conditions, it was 5.01 m (SD = 0.51). Analysis showed non-significant (p > 0.05) differences between measured jumps under both conditions.

**Discussion**

The main objective of this study was to identify differences in step length adjustment between the long jump with and without the take-off board. The results showed that the step length adjustment, identified by ascending-descending patterns of footfall placement, was different between conditions. The initial point of the step length adjustment (5th and 7th step before reaching the take-off board for TB and NTB, respectively) was found to be different between conditions (Fig. 1). The onset of step length adjustment under the TB condition was similar to previous findings, in which the descending trend in variability was found during the final five steps for non-long jumpers [9] and at different levels of experience [1, 13, 21]. The values of footfall variability between conditions were significantly different for most of the approach runs (Fig. 1). However, the values of footfall variability for both conditions, in relation to the previous findings, were similar to those observed for every level of experience [9] and higher than in elite athletes [1]. Consistent with the study of Scott at al. [9], this lower consistency of steps could be due to the lack of task-specific training. The subjects were not experienced in the long jump and had not practiced any training with an approach run before this investigation.

The proportion of step adjustments showed that under TB conditions, the greatest correction was made for the penultimate step and under NTB conditions, for the last step, before the take-off. The majority of the total step adjustments were spread over the final three steps. We observed that the percentage distribution of step length adjustment (Fig. 2) over the last three steps was similar under both conditions (overall value of 73.7% for TB and 74.8% for NTB, respectively). The results also showed that the subjects demonstrated similar patterns to those previously reported for different skill levels [6, 13, 21]. This may suggest that the absence of the take-off board changed the manner in which the subjects performed the last step. The significant modifications in footfall variability during the last step in NTB resulted in a lower foot placement precision at the take-off phase.

The early initiation of step length regulation and different consistency in step adjustments between conditions could be due to a function of task complexity [22, 12]. Task constraints nested in an approach run towards a target, changing the regulation of the step, depend on the task at the end of the run-up [17]. This seems to suggest that a subject’s locomotion during long jump performance under both conditions was controlled in terms of their goals. Under the NTB condition, there was no requirement to take off accurately at the board and the only goal was to jump as far as possible. Under such specific conditions, which involve a controlled approach run towards a spatial target area (i.e. long jump without the take-off board), the earlier step length adjustments could lead to better execution of the approach run [22]. This could also support the assumption regarding differences in locomotor pattern over conditions and continuous step control during the run-up in relation to the environment [13].

The similar difference in step length adjustment in relation to the goal of the approach run was previously seen between run-throughs and long jump performance [11, 12, 23, 24]. Different task requirements do not allow the jumper to provide any step adjustments until they are necessary. If the take-off from the board is not required, athletes may not be compelled to adopt a precise take-off foot position [12]. It is consistent with the present study, in which the subjects performing a long jump without the take-off board, made a last minute step adjustment. The majority of the last step corrections, compared to early onset of step regulation, resulted in lower foot precision at the take-off phase (see Fig. 1).

Comparison of the two conditions showed that they are not only different in terms of goals, but also in their step kinematics. The close characteristic of step lengths over the last part of the run-up were similar between conditions. The last step was shorter than the second-to-last step and the competitors demonstrated typical actions similar to those of professional jumpers during the final phase of the approach run [2, 3, 25]. This provides evidence that the conditions under which the subjects performed the approach run did not change their step patterns. However, we found that the length of the particular steps under NTB conditions was significantly longer during the whole approach run (Fig. 3). It was previously observed that when task constraints within a nested task increase, the step length tends to decrease [17, 23]. This could be an explanation for the present findings, in which the subjects under TB conditions did not only reach optimal horizontal velocity but they also had to be precise at the take-off board. In contrast, the subjects who were not constrained by the board at the end of the runway could focus only on maintaining horizontal velocity during the approach run. We suppose...
that these could also result in lower variability in footfall placement and the subjects were able to produce lengthened, consistent steps.

Maraj [11], in contrast, showed that the absence of the take-off board resulted in a constant increase in variability of footfall placement. This provided evidence that the last part of the approach run is under a subject’s visual control in relation to the board. This could be questionable in light of the present findings. The approach run towards the “virtual” target area requires accurate foot placement, so it allows the jumper to regulate step length in order to be optimally positioned to that area to maximize performance [22]. Despite the lack of constraint at the end of the runway and no requirement to place the foot precisely at the take-off, the subjects were still constrained by a sandpit which could not be overstepped. This fact may lead to increased visual perception because of the subject’s relation to the sandpit, which resulted in uniform adjustments over the following steps during the approach run. Nevertheless, we believe that the absence of the take-off board does not exclude the role of regulatory stimuli as an important part in guiding human locomotion [11, 12, 26].

Based on the present findings, we conclude that different task constraints under both observed conditions lead to a different pattern of the step length adjustments. The lack of environmental constraints at the end of the approach run (take-off board) could be helpful in producing constant steps. In addition, the simpler nested actions at the end of the approach phase, like in the long jump without the take-off, might enhance the ability to control the step by subjects and lead to lengthening particular steps. But on the other hand, this could also result in lower precision of footfall placement in the final phase of the approach run.

**Limitations**

There are limitations to the present study. Firstly, the participants were not experienced in long jump training. Future studies should examine performances under both conditions (with and without take-off board) in elite class jumpers to generalize findings from this study, which would help to clearly identify a pattern for step length adjustment. A second limitation of this investigation is that we showed differences in variability of footfall placement under each of the analyzed conditions without exploring if there is a connection with the long jump distance. To achieve a better understanding of movement variability during the approach run in the long jump, future research needs to examine the relationship between step length adjustment and performance of the long jump. This would provide valuable solutions for training routines.

**Conclusions**

The findings of the present study indicate that in order to maintain better foot placement at the take-off phase, the long jump should be performed from a precisely identified place (i.e. from the board). In order to develop consistent step patterns, coaches should implement the long jump without the take-off board into training routines. This may also be beneficial for lengthening particular steps in the approach phase.

**Acknowledgements**

This research is supported by the Ministry of Science and Higher Education within the project “Rozwój Sportu Akademickiego” [Development of Academic Sport] (No. RSA2 03452).

**References**

Step length adjustment in the long jump with and without take-off board in non-long jumpers


Address for correspondence:

Starzak Marcin
Department of Athletics
The Josef Piłsudski University of Physical Education in Warsaw
Faculty of Physical Education and Sport, Biala Podlaska, Poland
ul. Akademicka 2, 21-500 Biala Podlaska
e-mail: starzakmarcin@gmail.com
mobile: 48-602-230-467
CARDIORESPIRATORY RESPONSE AND ENERGY SYSTEM CONTRIBUTION DURING SPEED ENDURANCE WORKOUT IN A HIGHLY TRAINED SPRINTER: A PRELIMINARY REPORT

Krzysztof KusyABCDEFG, Ewa ZarębskaBC, Monika Ciekoł-SoltysiakBC, Michał JanowskiBC, Jacek ZielińskiABDEG

Department of Athletics, Poznan University of Physical Education, Poland

Keywords: speed endurance, aerobic energy contribution, ventilation, blood lactate, track session

Introduction

Physical efforts performed at maximal or near-maximal speed are crucial for success in many sports. Sprint running is the most obvious example. Such exercise is typically associated with anaerobic metabolism. In spite of this common opinion, previous studies demonstrated that the involvement of aerobic energy supply may vary from 3% to 64% during all-out exercise of a duration from 6 to 90 s [1, 2, 3, 4, 5, 6, 7]. The contribution of aerobic metabolism in 100-m and 200-m sprints has been estimated to be about 3–7% and 14–29%, respectively [8, 9, 10].

However, it should be noted that almost all data obtained hitherto were based on cycling [1, 2, 5, 6, 7] and treadmill running [9], which do not strictly reflect the specificity of track running, or on mathematical models with their simplified assumptions [4, 6, 8, 10]. The study
of Duffield et al. [11] is probably the only one in which actual track running was used. According to their data, the relative aerobic energy contribution for the 100-m event, as measured by accumulated oxygen deficit, was 21% for males and 25% for females, or 9% and 11%, respectively, based on lactate and phosphate creatine (PCr) measurements. Today, it is clear that virtually all physical activities derive some energy from each of the following three processes: (i) splitting the high-energy PCr, (ii) the nonaerobic breakdown of carbohydrates and (iii) the combustion of carbohydrates and fats in the presence of oxygen [12]. It was also revealed that the time from the onset of a high-intensity exercise to the onset of oxidative processes is shorter than previously believed [12], and that oxygen consumption following a repeated sprint exercise may equal the peak values obtained during a graded test until exhaustion [13].

The assessment of cardiorespiratory response and energy contribution from aerobic and anaerobic sources in competitive speed-power athletes is of great practical interest. Speed endurance is a crucial ability resulting in maintaining a high running speed that tends to decrease in the second/final stage of the 100-m or 200-m distance. The common but unjustified assumption is that very short all-out sprints only activate anaerobic mechanisms of energy production. In fact, even a single sprint exercise triggers aerobic energy sources as well, the contribution of which may increase with each subsequent repetition [13]. Thus, measuring indices of aerobic and anaerobic energy sources provides the coach and athlete with information on the adequacy of the training loads used and gives the opportunity for their optimization (exercise and recovery time, number of repetitions).

To our best knowledge, no data have been published about cardiorespiratory aerobic response to a speed endurance workout and aerobic energy contribution obtained during an actual training session. Thus, the aim of this report is the assessment of the magnitude and time of the response to individually programmed sprint intervals in a highly trained sprinter. We hypothesize that the aerobic response and aerobic energy contribution to speed endurance session will be noticeable despite the assumption regarding the anaerobic character of the exercise.

**Methods**

**Subject**

The athlete was a male sprinter, aged 23 years, a member of the Polish national team, specializing in sprints 100 m, 200 m and 4 × 100 m for eight years, whose body height was 183 cm, body mass 80.4 kg and relative fat content 9.5% as measured by dual X-ray absorptiometry (Lunar Prodigy, GE Healthcare, USA). His personal best performances were: 6.63 s (60 m), 10.38 s (100 m), 20.89 s (200 m) and 38.60 s (4 × 100 m). The project, part of which is this study, has been approved by the Ethics Committee at the Karol Marcinkowski Medical University in Poznan.

**Graded exercise test**

Before the competition period, the athlete underwent an incremental running treadmill test (Pulsar, h/p/cosmos, Germany) until exhaustion in order to obtain physiological characteristics during maximal endurance exercise. The test was completed at the “Labathletics” Human Kinetics Laboratory of the Poznan University of Physical Education, in the morning, about 2 h after consuming a light breakfast (bread and butter, water, without coffee or tea). Before the trial, the analyzers were calibrated with standard gases of known concentrations and volumetric calibration was done. Main cardiorespiratory variables were measured continuously (breath-by-breath) by means of the MetaMax 3B-R2 ergospirometer and the MetaSoft Studio software (Cortex Biophysic, Germany): breathing frequency (BF), tidal volume (VT), minute ventilation (VE), oxygen uptake (VO2), carbon dioxide production (VCO2), respiratory exchange ratio (RER), heart rate (HR) and oxygen pulse (VO2/HR). Baseline VO2 was established during the last 10 min of a 30-min pre-exercise rest period. Then, the athlete started the test at a speed of 4 km/h and walked for 3 min. Subsequently, the speed was progressively increased by 2 km/h every 3 min until volitional exhaustion. The athlete was verbally encouraged to give maximal effort throughout the test.

Maximal heart rate (HRmax) was defined as the highest value recorded during the test. Maximal oxygen uptake (VO2max) was considered to be achieved if the test met at least three of the following criteria [14, 15, 16]: (a) a plateau in VO2 with increasing speed; (b) respiratory exchange ratio > 1.15; (c) heart rate within 5 beats/min of the age-predicted HRmax [17], (d) blood lactate concentration after exercise greater than 7 mmol/L and (e) the rating of perceived exertion was 19 or 20 as indicated by the athlete on the Borg Scale [18]. VO2max was expressed in ml/min (absolute values) and in ml/kg/min (relative to body mass). Maximal oxygen pulse was derived by dividing VO2max by HRmax. Venous blood samples were obtained from the antecubital vein at rest and immediately after the maximal test. Lactate concentration was assayed using chip sensor technology (Biosen C-line analyser, EKF Diagnostics, Germany/USA).

**Track session**

The measurements were performed during the taper phase before the main competition on a standard 400-m running track during windless weather and the air temperature at 26°C. The aim of the session was to develop speed endurance. The session was designed by a coach...
and included the following main parts: (i) a 40-min warm-up (jogging, stretching, skipping drills and other technique drills, preliminary “run-throughs” at increasing speed), (ii) four maximal sprints from a standing start 60 m + 60 m + 100 m + 120 m followed by passive recovery and (iii) a 30-min cool-down (stretching, jogging). Actual recovery times between the sprints slightly differed from the planned ones and were 5 min 5 sec. (vs. the planned 5 min) after the first 60 m, 7 min 40 sec. (vs. the planned 8 min) after the second 60 m, 8 min 6 sec. (vs. the planned 8 min) after the 100-m sprint and 10 min 27 s (end of recording data) after the 120-m sprint. The wireless mobile ergospirometry system was worn by the athlete during the main part (ii) of the session, consisting of maximal sprints, that lasted for 35 minutes. During this time, cardiorespiratory variables were measured using the same methods and apparatuses as in the laboratory (see above). Capillary blood for lactate concentration was obtained from the finger tip immediately before the session, after the warm-up and 3 min after the last sprint. Sprint times were measured automatically to the nearest 0.01 s using photocells (Brower Timing TC-System, USA).

Energy contribution calculations

The calculations were performed according to the algorithm suggested by Beneke et al. [19]. In brief, net aerobic energy was calculated from the VO₂ above baseline during each sprint. We assumed the O₂ equivalent equal to 21.1 kJ/l. The energy produced from anaerobic alactic metabolism was estimated from the fast component of post-exercise oxygen consumption (EPOC) and the O₂ equivalent. The times of collecting EPOC data were the same as recovery times after consecutive sprints (see above). The time course of VO₂ during recovery after each sprint was fitted into a bi-exponential curve based on the following equation:

$$VO_2(t) = A_f e^{-t/\tau_f} + A_s e^{-t/\tau_s} + VO_2\text{base}$$

where $VO_2(t)$ is oxygen consumption at time $t$, $A_f$ and $A_s$ are amplitudes of the fast and slow component, respectively, $\tau_f$ and $\tau_s$ are corresponding time constants and $VO_2\text{base}$ is oxygen consumption at baseline. The fast component of EPOC was calculated as the product of $A_f \tau_f$. The bi-exponential model was constructed using OriginPro software, version b9.3.226 (OriginLab Corp., USA). Net energy produced from anaerobic lactic acid metabolism was determined from net lactate concentration (post-exercise minus pre-exercise), body mass and $O_2$-lactate equivalent. The latter was assumed to be 3 ml $O_2$/kg/mmol/l, i.e. 63 J/kg/mmol/l. Aerobic and anaerobic alactic energy production was estimated for each sprint separately, whereas anaerobic lactic acid energy contribution was calculated as one total value (lactate concentration was measured before the first and after the last sprint).

Results

The comparison between peak cardiorespiratory variables obtained at $VO_2\text{max}$ during the laboratory graded test versus the speed endurance track session are shown in Table 1. In Figures 1–4, the detailed time

| Table 1. Exercise characteristics at maximal oxygen consumption during a laboratory treadmill test until exhaustion (LAB) and peak values after consecutive sprints during track session (TRACK). Percentage of maximal laboratory values is shown in brackets. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | LAB             | TRACK           |                 |                 |                 |
|                 |                 | 60 m            | 60 m            | 100 m           | 120 m           |
| Time [s]        | 888             | 6.76            | 6.68            | 10.85           | 13.06           |
| Av. speed [m/s] | –               | 8.88            | 8.98            | 9.22            | 9.19            |
| VE [l/min]      | 137.3           | 87.8 (64%)      | 107.1 (78%)     | 104.0 (76%)     | 109.9 (80%)     |
| VT [l]          | 2.08            | 2.15 (103%)     | 2.07 (99%)      | 2.14 (103%)     | 2.15 (103%)     |
| BF [/min]       | 66              | 44 (67%)        | 56 (85%)        | 63 (95%)        | 73 (111%)       |
| VO₂ [/min]      | 3.72            | 2.77 (74%)      | 2.95 (79%)      | 2.91 (78%)      | 2.80 (75%)      |
| VCO₂ [/min]     | 4.37            | 3.13 (71%)      | 3.19 (72%)      | 3.22 (73%)      | 3.10 (70%)      |
| RER             | 1.05            | 1.28 (122%)     | 1.47 (140%)     | 1.44 (137%)     | 1.32 (126%)     |
| EPOC [/min]     | 3.49            | 2.54 (72%)      | 2.72 (77%)      | 2.68 (76%)      | 2.57 (73%)      |
| HR [/min]       | 194             | 162 (84%)       | 166 (86%)       | 172 (89%)       | 174 (90%)       |
| VO₂/HR [ml]     | 19.2            | 17.1 (89%)      | 17.8 (93%)      | 16.9 (88%)      | 16.1 (84%)      |
| LA [mmol/l]*    | 11.0            | –               | –               | –               | 16.2 (147%)     |

* venous blood in laboratory, capillary blood during track session

Abbreviations: BF breathing frequency; EPOC excess post-exercise oxygen consumption; HR heart rate; LA blood lactate; RER respiratory exchange ratio; VCO₂ exhaled dioxide; VE minute ventilation; VO₂ oxygen uptake; VO₂/HR oxygen pulse; VT tidal volume
courses of main cardiorespiratory parameters are presented. A clear increase in all parameters was observed after each sprint. VE increased from 64% of the value at VO$_{2\text{max}}$ following the first (60 m) sprint to 80% following the last (120 m) sprint. Similarly, BF increased from 67% to 111% of the value at VO$_{2\text{max}}$. The increase in VT was similar across the four sprints (up to 99–103% of its value at VO$_{2\text{max}}$). VO$_2$ and VCO$_2$ reached between 70%
Cardiorespiratory response and energy system contribution during speed endurance workout...

and 79% of their maximal values. HR and VO2/HR approached 84–90% of maximum value. Post-effort RER reached 122–140% of the value at VO2max.

The times of reaching peak values following the sprints were different depending on the parameter and successive sprints (Table 2). Peak VE and BF were attained within a narrow time range between 37 s and 46 s and 23 s and 34 s, respectively. The time to reach peak VT increased with each consecutive sprint from 38 s to 67 s. Similarly, the times to attain peak VO2, VCO2, RER, HR and VO2/HR values increased with each sprint from 46 s to 89 s, 47 s to 76 s, 175 s to 196 s, 36 s to 48 s.

Figure 3. Time course of heart rate (HR, purple line) and oxygen pulse (VO2/HR, green line) during an actual speed endurance track session in a highly trained sprinter. Vertical yellow lines denote the start and completion times of consecutive sprints.

Figure 4. Time course of respiratory exchange ratio (RER) during an actual speed endurance track session in a highly trained sprinter. Vertical yellow lines denote the start and completion times of consecutive sprints.
and 45 s to 77 s, respectively. During the recovery intervals, all cardiorespiratory variables returned to pre-exercise values but maintained significantly above baseline (resting) values (Fig. 1–3). Pre-exercise LA was 1.90 mmol/l and following the warm-up, 2.88 mmol/l. Peak LA, measured after the last sprint, reached 147% of the maximum value measured during the maximal graded test until exhaustion (Table 1).

Table 2. Times to reach the peak values* after consecutive sprints (seconds)

<table>
<thead>
<tr>
<th></th>
<th>60 m</th>
<th>60 m</th>
<th>100 m</th>
<th>120 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>VE</td>
<td>46</td>
<td>37</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td>VT</td>
<td>38</td>
<td>40</td>
<td>52</td>
<td>67</td>
</tr>
<tr>
<td>BF</td>
<td>27</td>
<td>34</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>VO₂</td>
<td>46</td>
<td>54</td>
<td>66</td>
<td>89</td>
</tr>
<tr>
<td>VCO₂</td>
<td>47</td>
<td>56</td>
<td>76</td>
<td>74</td>
</tr>
<tr>
<td>RER</td>
<td>175</td>
<td>185</td>
<td>218</td>
<td>196</td>
</tr>
<tr>
<td>HR</td>
<td>36</td>
<td>43</td>
<td>53</td>
<td>48</td>
</tr>
<tr>
<td>VO₂/HR</td>
<td>45</td>
<td>56</td>
<td>77</td>
<td>63</td>
</tr>
</tbody>
</table>

* time from the start of the sprint until obtaining post-exercise peak value

Table 3. The contribution of aerobic and anaerobic energy sources to the energy expenditure during four consecutive sprints

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Consecutive sprints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 m</td>
<td>60 m</td>
</tr>
<tr>
<td>Exercise VO₂ [l]</td>
<td>0.83</td>
<td>0.05</td>
</tr>
<tr>
<td>Energy from aerobic metabolism VO₂ [kJ]</td>
<td>17.54</td>
<td>1.08</td>
</tr>
<tr>
<td>EPOC, fast component [l]</td>
<td>3.08</td>
<td>0.34</td>
</tr>
<tr>
<td>Energy from anaerobic alactic metabolism [kJ]</td>
<td>73.62</td>
<td>7.57</td>
</tr>
<tr>
<td>∆ LA [mmol/l]</td>
<td>13.32</td>
<td></td>
</tr>
<tr>
<td>Energy from anaerobic lactic acid metabolism [kJ]</td>
<td>67.47</td>
<td></td>
</tr>
<tr>
<td>Total energy [kJ]</td>
<td>158.63</td>
<td></td>
</tr>
<tr>
<td>Energy contribution [%]:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– aerobic</td>
<td>11.1</td>
<td></td>
</tr>
<tr>
<td>– anaerobic alactic</td>
<td>46.4</td>
<td></td>
</tr>
<tr>
<td>– anaerobic lactic acid</td>
<td>42.5</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BF breathing frequency; HR heart rate; RER respiratory exchange ratio; VCO₂ exhaled dioxide; VE minute ventilation; VO₂ oxygen uptake; VT tidal volume

Discussion

The main finding of this report is that, as expected, repeated sprints performed during an actual track session in a highly trained sprinter elicited a strong cardiorespiratory response and aerobic metabolism noticeably contributed to the total energy production. Although anaerobic energy sources were estimated to deliver as much as ~89% of the total energy during the whole sprint workout, the remaining ~11% were provided by aerobic metabolism. Our results are, in general, consistent with studies in which the aerobic energy contribution during sprint exercise (6–20 s cycling or 100-200 m running) was estimated to be 5–18% [1, 4, 5, 10]. However, the reported results are affected by measurement and calculation methods and, for a 100-m sprint, may vary from 9% to 11%, based on lactate and phosphate.
Cardiorespiratory response and energy system contribution during speed endurance workout... 

The magnitude and delay of respiratory response was dependent on the measured variable and sprint order. The strongest respiratory response, reaching or exceeding the intensity at VO2max, was revealed for VT, BF and RER. The remaining cardiorespiratory variables attained submaximal levels (70–90% of values at VO2max). Similar relative values were found in healthy young men (21 ± 2 years) performing a single sprint on a cycle ergometer [20]. Time to reach peak VO2, VO2/HR, VCO2, RER, VT and BF increased with consecutive sprints, whereas it was relatively constant for VE and HR. The respiratory reaction was accompanied by a very high concentration of blood LA immediately after the last sprint and changes in proportion of aerobic and anaerobic alactic sources of energy.

Ventilation

Interestingly, VE (a product of VT and BF) increased to submaximal values after consecutive sprints despite “supramaximal” increases in BF and VT. The explanation is the desynchronization of VT and BF. These two peak values, even if extremely high, did not overlap: peak BF was attained sooner than peak VT. Peak magnitudes of VT were constant but the times to reach peak VT became longer with each subsequent sprint. In contrast, peak BF increased with subsequent sprints at constant peak times. As a result, VE reached values below those at VO2max (Table 1, Figure 1).

Oxygen uptake

In recreationally trained subjects, it was found that brief, all-out sprint interval exercise produced significantly higher values of post-exercise VO2 in magnitude and duration than after moderate aerobic exercise [21]. The literature concerning the respiratory response to a single or repeated sprint exercise in highly trained athletes is very scarce and, to our best knowledge, virtually no attempts were made to assess the response during actual track and field training sessions. In the study of Duffield et al. [11] on club- and national-level sprinters, peak VO2 and peak HR after a single 100-m sprint attained 33% VO2max and 91% HRmax. The observed VO2 was clearly lower than that attained by our athlete. The discrepancy is connected with different criteria to determine peak values: the end of sprint distance in Duffield et al. [11], and delayed post-exercise maximum value in this study. However, peak HR was similar despite different measurement assumptions because HR increased faster than VO2, already at the very early stage of exercise. McGawley and Bishop [13] measured oxygen uptake during two bouts consisting of five consecutive 6-s sprints on a cycle ergometer in female European football players (national league). VO2 increased to 93% (1st bout) and 102% (2nd bout) VO2max after the last sprint. In our study, peak VO2 after each consecutive sprint was lower and equal to 74–79% VO2max, even though the distance and exercise time increased. The differences may be attributed to recovery times between sprints, which were only 24 s in the study by McGawley and Bishop, and 5–10 minutes in our track session. Incomplete recovery results in the start from an elevated baseline. This in turn causes the increase in peak VO2. The longer recovery periods in our study brought about a return to VO2 levels from before the first sprint. Consequently, post-sprint peak VO2 values did not reach the VO2max level (Table 1). However, pre-exercise values were attained later, after each subsequent sprint.

Blood lactate

In this study, peak LA after the last sprint was high (16.2 mmol/l) and comparable to the levels observed by Locatelli and Arsac [8] after single 100-m sprints performed by competitive athletes during an actual competition. Such a high blood LA concentration is characteristic of so called “anaerobic lactic training”, which is a classic method in developing speed endurance. In fact, a considerable contribution of aerobic metabolism must be taken into account (see section below). The explanation of high blood LA levels during intense exercise is that phosphate sources (mainly PCr) become depleted, causing acidosis [22] and reduced glycogenolysis [23].

In practical terms, the levels of LA after a sprint exercise depend on the time and number of repetitions, as well as recovery duration. In healthy young males, peak values in LA were 4.4 mmol/l after a single sprint (cycling), 7 mmol/l after five 10-s sprints and 8.7 mmol/l after a 30-s sprint [24]. It was revealed that when multiple sprints were performed, the first of the ten 6-s sprints resulted in a small increase in blood LA to about 2 mmol/l, after the fifth sprint LA increased to 9.3 mmol/l, and after the ninth sprint LA reached 12.6 mmol/l and remained constant during the 10 min of post-exercise recovery [25]. In trained athletes, after a single 100-m actual track sprint, peak LA reached values from 8 to 16 mmol/l [8, 11, 26], which is consistent with our data. Hirvonen et al. [26] revealed that post-exercise blood LA levels increased with the distance and time of single sprints: 40-m, 60-m and 80-m track sprints elicited lactate responses equal to 4.5, 5.9 and 7.8 mmol/l, respectively. Thus, blood LA levels are higher when the distance, time and repetition number of sprints are higher and the recovery time is shorter. It is also suggested that highly-trained athletes can produce and tolerate higher lactate concentrations [27]. Based on the previous reports mentioned above, we may conclude that the LA levels in our sprinter were typical for a highly trained athlete.
Aerobic energy contribution

Sprint interval training sessions are typically aimed at stimulation of anaerobic energy sources using maximal or submaximal short-duration exercise separated by recovery periods. However, a substantial "admixture" of aerobic metabolism must always be taken into account, which seems to be unavoidable as demonstrated previously (see Introduction). The clearly noticeable contribution of aerobic metabolism as early as a few seconds from the beginning of a sprint exercise results from the fact that anaerobic energy sources get near their limits very quickly and need time to restore after exercise. That is why the recovery time and number of repetitions are crucial to the effects of such a specific session. Dawson et al. [28] found that in trained subjects, PCr repletion after a 1 × 6 s sprint was approximately 70% complete after 30 s of recovery and almost complete (90%) after 3 min of recovery. After 5 × 6 s sprints, each separated by only 24 s, PCr repletion was less than 50% complete after 30 s of recovery and only approximately 80% complete after 3 min. Full recovery from a multiple sprint exercise usually requires about 30 min for VO_{2} and blood LA levels to decline to resting values [21]. Admittedly, in our athlete, recovery times (5–10 min) allowed VO_{2} and other cardiorespiratory parameters to return to pre-exercise values, but post-exercise times to reach peak VO_{2} lengthened with each sprint and the aerobic energy demand increased. Simultaneously, the contribution of alactic anaerobic energy metabolism decreased, which suggests that full recovery of PCr was not possible.

The contribution of aerobic metabolism may increase from ~10% to ~40% of the whole energy delivery with each successive sprint separated by short recovery intervals [13]. It is related to a decrease in anaerobic adenosine triphosphate (ATP) resynthesis by 65% after multiple sprints [25], 88% to 100% of muscle PCr is expended during 5.5 s in a 11-s sprint, depending on an athlete’s performance level, and glycolysis is the main anaerobic energy source at the end of the run [26]. However, these both sources are still insufficient. Thus, it is suggested that, based on exercise protocols with short recovery intervals up to 30 s, aerobic energy contribution serves to offset the decline in anaerobic energy production during a repeated sprint exercise [13, 25, 29].

In support of the above view, the decline in power output is much smaller than the decrease in muscle PCr concentration and smaller than the decline in ATP production rate from anaerobic sources [13, 25]. In other words, sprint performance level is maintained in spite of the significant depletion of anaerobic sources. Such a phenomenon, although to a lesser extent because of relatively long recovery periods, was observed in our athlete. On the one hand, the contribution of aerobic metabolism increased and anaerobic (alactic) metabolism decreased with each repetition. On the other hand, the level of performance was maintained as measured by average running speed. From this point of view, the analysed speed endurance workout was properly planned and performed. However, this and other studies impose some questions: Which is the most optimal strategy for developing speed endurance ability? Should we strengthen the aerobic metabolic adaptation in order to offset the rapidly declining anaerobic capacity? Or vice versa: Should we mainly promote anaerobic capacity to extend the time during which anaerobic metabolism is efficient enough? Each of the approaches require a different workout programme as regards distance/time, number of repetition and recovery intervals. We speculate that each athlete has his/her own proportion of aerobic and anaerobic metabolism in a particular exercise that results in best performance (highest running speed). Modern measurement methods and knowledge enable coaches and researchers to determine such parameters for individual athletes. This study shows one of such ways. Future research should focus on algorithms that would help to precisely tailor speed-endurance exercise parameters to the needs of a highly-trained athlete.

Limitation and strengths

The main limitation of this preliminary report is that only one athlete was examined and the results cannot be generalized. However, the training of highly competitive athletes is strictly tailored to individual needs, hence they usually perform different training drills as was the case here. Also, some unexpected oscillations of respiratory variables that could obscure the calculations were observed, resulting from non-standard behaviour of the athlete in contrast to laboratory conditions. Moreover, the maximal test was performed much earlier than the track session, however, we revealed in our previous study that VO\textsubscript{max} did not significantly change in sprinters between the pre-competition and competition phase of the annual training cycle [30]. The strength of our report is that accurate and precise measuring methods were used during the actual track session, which allowed for the collection of unique data.

Conclusions

The athlete we studied showed typical contribution of aerobic (~11%) and anaerobic (~89%) energy delivery during the speed endurance workout. Our observations are consistent with evidence from other studies and support the notion that specific speed endurance exercise relies on both anaerobic and aerobic metabolism. The
latter seems to be inseparable from the training routine aimed at development of this ability in highly trained sprinters. The monitoring and control of actual track sessions using high-tech equipment may help coaches and athletes to determine optimal workout parameters, i.e. exercise and recovery time as well as repetition number, to effectively achieve training goals.

Acknowledgements

This work was funded by the Polish Ministry of Science and Higher Education from financial resources within “The Development of Academic Sports” programme, grant number RSA2 041 52. Special thanks to Tadeusz Osik, the coach of the Polish national team, and his athletes.

References


Corresponding author:
Krzysztof Kusy
Department of Athletics, Poznan University of Physical Education
e-mail: kusy@awf.poznan.pl
phone: +48 83 55 270
Abstract

Study aim. Review of literature related to handball reveals that modern handball performed at the highest level of competition is dominated by short-term, 5–20 second sequences of anaerobic efforts. Given the above data and lack of scientific reports describing the level of anaerobic capacity in handball players representing a high sports level, it was considered appropriate to investigate the efficiency of this field of capacity in the men’s premier league team. The aim of the study was to assess the relative mechanical work (J/kg) and maximal power (W/kg) obtained in the Wingate test, and to measure tissue components (BMI, FAT%, TBW%).

Study design. Subjects: 16 handball players from the premier league team. The average age of subjects = 25.33 ± 7.05 years, mean body height = 192.40 ± 7.18 cm, mean body mass = 98.31 ± 12.82 kg. Anaerobic capacity assessment was carried out in accordance with the Wingate – 30 s testing procedure, using the Monark 824E bicycle ergometer, and the MCE v. 5.0 computer program. Measurement of body tissue components were made using the Tanita SC330 body composition analyzer.

Results. The average maximum power was – 11.15 ± 0.80 W/kg, average work – 253.88 ± 16.93 J/kg, average time of attaining power – 4.83 ± 0.81s, time of maintaining power – 3.06 ± 1.08 s. The average BMI was 26.45 ± 1.91; FAT% – 12.92 ± 3.27; TBW% – 59.02 ± 2.43.

Conclusions. In the process of training handball at a high competitive level, more attention should be paid to the development of anaerobic endurance by increasing the share of interval-type loads.

Introduction

Handball is a sports discipline in which the ability to perform repetitive, short-term sprints of maximal intensity is of decisive significance [1, 2]. In the course of the game, the exercise load is characterized by the repetition of short-term high intensity efforts, such as runs, jumps, throws, which are separated by efforts of low intensity [3]. Success in hand ball is largely dependent on an increase in exercise capacity that can be obtained through special preparation and adequate development of motor skill levels [4].

During intense exercise, skeletal muscle work is based on anaerobic processes, which are the dominant source of energy [5, 6]. Scientific studies have shown that the ability to perform high intensity repetitive efforts depends on the phosphocreatine resources in the muscles and the speed of their re-synthesis [7]. The rate of phosphocreatine re-synthesis is dependent on aerobic metabolism, suggesting that players characterized by a higher level of VO2max index values are more prone to effective re-synthesis of the compound [8]. The ability of muscles to perform another intense effort depends at least in part on the rate of re-synthesis of phosphor-
creatinine and the rate of elimination of hydrogen ions. PCR resources are quickly restored (30–60 seconds), while the elimination of H+ takes much longer (5–10 min) [9].

In modern handball, an important component of the match load structure is an aerobic exercise capacity [10]. Studies on the “match” load structure by Czerewinski [11, 12] and Norkowski [13, 14] have proven that in the case of handball, 30–35% of the game time occurs in the area of anaerobic efforts. Therefore, the share of efforts characterizing anaerobic metabolism, their structure and proportions incline to carry out the content of training in accordance with the physiological characteristics of handball. In the available domestic and foreign literature, there is little data on anaerobic capacity of handball players representing a high level of competitive sports. Measurements of body composition are important in the assessment of nutritional status, as well as assessing the risk of developing illnesses related to irregular body fat contents [15]. Increased content of FAT is the main factor causing an increase in the level of TC, LDL-C and TG concentration, while FFM value significantly affects HDL-C concentration and TG in the serum [16,17]. Physically active individuals, e.g. athletes, gain benefits important for their health, such as normalization of body mass and maintenance of appropriate balance between lean body mass and body fat [18,19]. Water in the body is the single most important component of body mass. All cells in the body can function properly only when the it has an appropriate amount of water. Knowledge on fat and water contents in the body can provide some kind of guidance when adjusting a diet, fitness program or fluid intake, and thus can contribute to improving health status [20].

The aim of this study was to assess the level of selected anaerobic capacity indicators and body tissue components in handball players at a high level of competitive sports. Based on analysis, observation of championship competitions and the results obtained in them, the following hypothesis was put forward: “The handball team is not properly prepared for competition in terms of anaerobic capacity”.

Study design

Study participants: 16 players from the KS Azoty Puławy team. The average age of subjects = 26.53 ± 3.36 years, mean body height = 192.40 ± 12.82 cm, mean body mass = 98.31 ± 7.18 kg. The research was conducted during the starting period, on 6 Oct. 2014 in the laboratory of the Physical Culture Centre at Maria Curie-Skłodowska University in Lublin. The Wingate Test consisted of performing a 30-second, maximal effort on a bicycle ergo meter with an individually selected load of 7.5% of body mass [21, 22, 23]. The test was performed after a 5-minute warm-up on the ergo meter and after a 5-minute rest following the effort.

The study used the Monark 824E Cyklo Ergometr (Sweden), connected to an IBM PC Pentium computer, and the MCE_v_5.1 computer program [23]. Rotation sensors were fixed to a flywheel. During one revolution of the pedals, the flywheel performed 3.70 of a revolution, which corresponded to a distance of 6m. After establishing proper seat and handlebar height, the participant performed the effort seated, starting the effort from an immobile position. Their feet were fastened to the pedals. During the exercise, the participants were motivated to perform maximal speed of pedal rotation as quickly as possible, and to maintain it until the end of the effort. Using MCE_v_5.1., the following measurements and calculations were taken:

• number of flywheel revolutions,
• the value of the performed effort (J/kg),
• average power (W/kg),
• maximal power (W/kg),
• time of attaining P max (s),
• time of attaining P border (s),
• time of maintaining P border (s).

The Wingate test was chosen because it is a generally useful laboratory test used to assess muscular strength, muscular endurance, and its fatigue. Wingate has also found application as a test, which helps to analyze the physiological response of the organism to super maximal efforts [24]. The Wingate is a reliable test and when performed on the same day, the correlation coefficient is 0.95–0.98, and within 1–2 weeks, 0.90–0.93 [24]. Also, high correlation coefficient scan be observed between the Wan T. results and the results of other tests: anaerobic performance – sprint 40 m – 0.86; anaerobic endurance-swimming 25 m – 0.87–0.90; anaerobic power – the Margaria-Kalamen power test – 0.79 [25].

Body composition was assessed by bioelectrical impedance (using the body composition analyzer – Tanita SC330, Japan), fat-free mass (FFM%) was determined, as well as body fat (FAT%) and total body water (TBW%) [26]. The obtained results were statistic ally elaborated, calculating arithmetic means (x), standard deviations (SD), as well as minimal (min.) and maximal (max.) values All calculations were performed using SPSS v. 20 [27].

Results

As it may be assumed from the data provided during Tab. 1 the stress test, relative mechanical work performed by the athletes reached the average level according to the classification by Norkowski and Noszczak
In contrast, the average value of maximal power attained by the subjects was at a good level. The average value of maintaining borderline power was considered as a good result. Also, the average index of power decrease, calculated as the percentage difference between maximal power and minimal output recorded after attaining the maximal power, reached an average level.

According to the data in Tab. 2, the average value of the BMI of the subjects was super-standard. The average value of percentage of fat issue content sand water in body mass of the athletes, fell within the range of values considered as normal.

### Discussion

In handball, maintaining a high intensity of playing is only possible in the case of having high anaerobic and aerobic potential [29, 13]. High tolerance of the match effort is always better in athlete shaving a high VO2max index value and anaerobic endurance. It is recommended that the level of aerobic and anaerobic capacity should be under constant control. Reduction below 54ml/kg/m² in [30] in the case of aerobic capacity, and below 10.83 W/kg [28] in the case of anaerobic capacity, poses a significant limitation for specialized training of handball players. The ability to adjust the structure of training loads to starting loads is a key issue in the training process. Czerwinski [29] showed that the level of training intensity in handball is much lower than that observed in competitive conditions.

The most frequently mentioned cause is organizational failure in technical-tactical exercises, which are not sufficiently strong enough exercise stimulus from the point of view of adaptation to the actual conditions of the game. The results of the study by Norkowski [13, 14] suggest that the problem is related to the low effectiveness of methods for developing anaerobic capacity implemented in the exercises; their structure and organization do not correspond to physiological criteria of maximal anaerobic efforts. The cited authors present a consensus view that a direct consequence of inadequate training in anaerobic capacity is low tolerance of the body to repeated lactate-type efforts. An indication of this state area cute manifestations of fatigue during the game, which in turn have significant impact on lowering the effectiveness of offensive and defensive actions. The subjects from the KS “Azoty”

### Table 1. Average values of anaerobic capacity indicators in KS “Azoty” Puławy handball players

<table>
<thead>
<tr>
<th>N 16</th>
<th>Effort</th>
<th>Pmax.</th>
<th>TA</th>
<th>TM</th>
<th>PDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>253.88****</td>
<td>11.15****</td>
<td>4.83****</td>
<td>3.06***</td>
<td>24.84****</td>
</tr>
<tr>
<td>SD</td>
<td>± 16.93</td>
<td>± 0.80</td>
<td>± 0.81</td>
<td>± 1.08</td>
<td>± 3.62</td>
</tr>
<tr>
<td>Min.</td>
<td>228.42</td>
<td>9.73</td>
<td>3.73</td>
<td>1.45</td>
<td>17.88</td>
</tr>
<tr>
<td>Max.</td>
<td>278.61</td>
<td>12.65</td>
<td>6.36</td>
<td>5.97</td>
<td>31.50</td>
</tr>
</tbody>
</table>

Legend:
- TA – time of attainment
- TM – time of maintenance
- PDV – power decrease value
- **** average result
- *** good result

### Table 2. Average values of anthropometric and body composition indicators in KS “Azoty” Puławy handball players

<table>
<thead>
<tr>
<th>N = 16</th>
<th>Age</th>
<th>Body mass</th>
<th>Height</th>
<th>BMI</th>
<th>FAT %</th>
<th>TBW%</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>26.53</td>
<td>98.31</td>
<td>192.40</td>
<td>26.45</td>
<td>12.92</td>
<td>59.02</td>
</tr>
<tr>
<td>SD</td>
<td>±3.36</td>
<td>±12.82</td>
<td>±7.18</td>
<td>±1.91</td>
<td>±3.27</td>
<td>±2.43</td>
</tr>
<tr>
<td>Min.</td>
<td>20</td>
<td>83.50</td>
<td>178</td>
<td>24</td>
<td>7.50</td>
<td>55.60</td>
</tr>
<tr>
<td>Max.</td>
<td>34</td>
<td>120.50</td>
<td>202</td>
<td>30.10</td>
<td>17.30</td>
<td>62.90</td>
</tr>
</tbody>
</table>

Legend:
- BMI – body mass index
- FAT% – body fat
- TBW% – total body water

[28].
Pulawy team were subjected to diagnostic tests because of poor sports results obtained in the first 7 rounds of the 2014/2015 season. The study results confirmed the hypothesis that the team is not properly prepared for the season in terms of anaerobic capacity. The obtained results of the Wingate test, in which the maximal power value was an average 11.15 (W/kg), and the minimal and maximal values, respectively 9.73–12.65 (W/kg), classify the result as average in accordance with the previously cited authors [28]. A similar situation exists in the case of the results of time of attaining maximal power and then maintaining border line power.

The average values of time of maintaining borderline power were within the range of assessment considered as good, probably as a result of achieving poor results of maximal power and time of its attainment. Also determined as average was the percentage of value of percentage decrease in the power index, calculated as the percentage difference between maximal and minimal power registered after attaining maximal power [23]. Referring to the analysis of the preparatory period, it should be emphasized that the team’s preparation was on the basis of the training method. This method was not favourable for the anticipated effects of training. Despite the high intensity of training obtained during the control competitions, not all the athletes, and especially the “doubles”, participated in the practice for the same period of time.

It is probable that during the earlier period of preparation, inadequate time was also devoted to anaerobic capacity development training. The earlier cited results and examples of works on the development of anaerobic capacity, point to the importance of this sphere in the overall efficiency of an athlete’s energy potential. According to Jansen et al. [31], Karp [32] and Ryguly et al. [33], the primary method of developing and maintaining a high level of anaerobic capacity is interval training with a maximal intensity load, and according to Linossier et al. [34], the most effective means of impact are repetitive efforts lasting up to 10s. Regular, high intensity physical exercise with elements of interval loads cause greater changes in anaerobic and aerobic capacity, and also more beneficial modification of anthropometric and biochemical indicators, compared to endurance exercises of low or moderate-intensity [35, 36, 37, 38].

Studying the content of fat tissue in the body is greatly significant in evaluating nutritional status or the risk of development of illnesses such as: coronary heart disease, type 2 diabetes, hyperlipidemia [39, 40]. The results of measuring water content in the body depend on fat and muscle contents in body mass. If the fat content is high or when the content of muscles is low, the level of residual water content in the body can be low [18, 19]. The participating handball players presented normal percentage values of fat tissue and water in the body mass. The average value of BMI, which was at 26.45, may be suggestive of high content of muscle mass in body composition, which is confirmed by the results. The results presented in this study may serve as complementary knowledge regarding diagnosis of the training process in handball for teams performing at high competitive level of sports.

**Conclusions**

Based on the analysis of the obtained results, the following conclusions were formulated:

1. Selected indicators of anaerobic capacity obtained by the studied athletes using the Wingate test were at good and average levels, which did not guarantee obtaining high sport performance results in the handball premier league competition.
2. The studied handball players presented normal percentage values of fat tissue and water in the body mass.
3. In the process of practicing handball at a high competitive level, more attention should be paid to the development of anaerobic endurance by increasing the share of interval-type loads.

**References**


Selected parameters of anaerobic capacity and body tissue components in handball players...


[14] Norkowski H: Propozycja oceny wybranych cech potencjału beztlennikowego polskich piłkarzy i piłkarzy ręcznych. Trening nr 1, 2001; (49) s. 87–93.


**Address for correspondence:**

Krzysztof Krawczyk
20-554 Lublin, ul. Ułanów 1/13,
E-mail: k.krawczyk@poczta.umcs.lublin.pl;
Mobile: +48 607666686
THE INFLUENCE OF TWO-PERSON OFFICIATING ON THE RANGE OF MOVEMENT OF THE CERVICAL SPINE IN BASKETBALL REFEREES

Barbara Koperska¹ A B C D E F, Bartosz Trybulec² C E

¹ Orto-Sport Medical Office, Krakow, Poland
² Institute of Physiotherapy, Faculty of Health Sciences, Collegium Medicum, Jagiellonian University, Krakow, Poland

Keywords: range of movement of cervical spine, basketball, basketball referees, two-person officiating

Summary

Introduction: Basketball is the third most popular sports discipline in Poland. Officiating matches requires from the referees not only concentration and resistance to stress, but also high level of physical fitness, dictated by the intensity of the games.

Aim of study: To verify the extent and mode of the influence which two-person officiating, together with seniority have on the range of movement of the cervical spine in basketball referees.

Study design: The study was conducted among a group of 31 basketball referees from the Krakow, Silesian and Podkarpacki districts; an original questionnaire and a measurement record were used. The examination of the range of movement of the cervical spine was carried out with a measuring tape.

Results: Before the match, the average range of the passive bend was 5.70 cm for the left bend and 5.13 cm for the right bend ($p < 0.05$). The average range of the active bend was also significantly greater in the case of the right bend and equalled 5.16 cm (as opposed to the left bend, which equalled 4.66 cm at $p < 0.05$). The average range of active body extension before the match equalled 7.33 cm and decreased to 6.89 cm after the match ($p < 0.05$). The average range of the left head turn before and after the match was 8.74 cm and 8.20 cm, respectively ($p < 0.05$).

Conclusions: Two-person officiating greatly affects the range of movement of the cervical spine in basketball referees: they present lower range of movement in terms of active extension and active left turn after the match. Seniority affects positively the range of passive flexion of cervical spine.

Introduction

Basketball is one of the most widely practised sports in the world and because of that, a continuous, dynamic rise in demand for qualified referees can be observed. Basketball referees must not only respond quickly and make decisions under tremendous stress, they must also stay in excellent shape throughout the season. They work on their speed and strength, practicing several times a week at the gym, at the pool or jogging, all year round. The vast amount of work the referees put in preparation for the season is necessary due to how increasingly dynamic game basketball is. It is often the case that the players are half the age of the leading referee, nevertheless, the referee must match the players in shape, and often needs to be able to outrun them. A player may ask for a substitution at any time, as opposed to referees, who leave the court last. Therefore it seems reasonable to say that the expectations put on the referees may affect their musculoskeletal system [1, 2].

For the judges to effectively control the course of the game, the so-called mechanics of officiating were created. According to Dziudzik, “Mechanics of officiating is a developed system of practical methods of facilitat-
ing the work of the referees on the court. It helps the referees to find the best possible position from which they can observe the game and enables them to assess the violations and fouls correctly, and make decisions. Depending on the rank and degree of difficulty of the competition, there can be one, two or three referees on the court; hence two-person and three-person officiating mechanics can be distinguished [3].

In two-person officiating mechanics, the lead referee (or official) and an auxiliary referee can be distinguished. There is no difference between the referees as to the authority to decide about violations and fouls. The distinction comes from the fact that the main referee is responsible for matters related to the management of the game: s/he approves the court, technical equipment, s/he also describes in the protocol all the negative events on the court and off it (fouls, equipment malfunctions etc.). Modern officiating requires close cooperation between the two referees, one of them takes responsibility for observing the game with the ball, the other for the game away from the ball (s/he controls, for example, the behaviour of the post players). In order to help the referees avoid observing the same players or efforts, the so-called division of responsibility on the court was introduced. To have the best outlook on the court and players, the referees must try to find the best possible position to evaluate the game, in which the mechanics of officiating prove very helpful. To facilitate the division of responsibility between referees, half the court is divided into six rectangles numbered from 1 to 6 [4]. During the match, the referees, depending on their position in relation to players’ efforts, take the lead or the trail position. When the game moves towards the attacked basket, the trail referee should take the position behind the effort with the ball within 3 to 5 m from them, whereas the lead referee should always stay ahead of the game. They must be faster than the fastest defensive or offensive player, moving towards the end line as quickly as possible, thereby allowing the game to move in their direction. The lead referee takes the spot facing the observed effort or a pair of players. Both the lead and trail referees must be constantly moving. By dividing the pitch to 6 conventional parts, each referee knows exactly which players on the field they are responsible for (Fig. 1). And thus, the trail referee is responsible for observing the game with the ball when it is in zones 1, 2, 3, and part of the zone 6 (before the three-point line). The lead referee watches the game with the ball when it is in zone 4. Zone 5 and part of zone 6 (the two-point area) are parts for which the referees share responsibilities [3, 4].

During the match, when the attacking team changes (e.g. after scoring or a violation), also the referees take turns. This means that when the direction of the game changes, the trail referee becomes the lead and vice versa. The referees change their functions in this way from a dozen to several dozen times during the match [5]. If the movements of the referees are scrutinised, then we observe that every time the game changes direction the

![Fig. 1. Division of pitch zones according to referee’s responsibility [4]](image-url)
The influence of two-person officiating on the range of movement...

"new" lead referee has to make a maximal left turn of the head (Fig. 2) to watch the game behind him all the time. This referee always runs heading forward on the right side of the court. There is no clear situation in the match when the referee runs with his/her head twisted to the right. There are moments when they turn the head to the right, but it is rather in a static position, e.g. when in the first zone, they turn to the other referee to give them observations on their behaviour. It is clear from all of the above that the cervical spine in a two-person officiating referee is subjected to straining and asymmetrical, repetitive motor schemes [3, 4].

The aim of the study was to verify whether or not two-person officiating has significant influence on the active and passive range of movement of the cervical spine in basketball referees; if the relation exists, what kind of relation is it?; and whether or not there exists a significant relation between the range of movement of the cervical spine and seniority in officiating.

Study design

This study is preliminary in nature to a larger research project related to refereeing, therefore the research material was comprised of a group of 31 basketball referees (5 females and 26 males). 26 of the subjects officiate in the Krakow basketball district, while 3 referees work in the Silesian district and 2 work in the Podkarpacki district. 9 participants officiate at the central level, 11 of them are I class referees and 11 are II class referees. The average age of the subjects was 31.7 years, the average height 180.39 cm and average body mass 83.05 kg. The average BMI for the referees was 25.37. The shortest seniority was 3 seasons, and the longest lasted 24 seasons – which gave an average of 10.63 seasons. Full data on the study group are presented in Table 1.

Tests were carried out in the second half of the 2013/2014 season – from 1st February to 14th June 2014. The study was carried out on both league matches (20) and amateur matches (11 matches in the KNBA league). The matches included the league tournaments in the Krakow basketball district as well as nationwide tournaments (Polish Cadets Championship Semifinals, Voivodeship Teams Tournament, Polish Junior Championship Quarter-finals). Research tools included a questionnaire and an original range of movement measurement record. A measuring tape, as a clinically accepted tool, was used to measure the range of movement in the cervical spine [6]. Before performing measurements, all subjects were informed about the objectives of the project and the methods. Written consent from the referees was a necessary condition for the examination to begin.

Fig. 2. Dominant position of cervical spine in the two-person officiating technique
The original questionnaire covered general information about the subjects (age, height, weight) and included questions about officiating matches on the court. The aim of the questionnaire was to obtain information: what is the subject’s seniority, which officiating mechanics do they use most frequently and in which tournament classes can they officiate, etc.

Height, weight, the number of seasons (seniority) and the date, place and time of the examination were put in the record. In addition, the record included tables in which ranges of active and passive movements before and after the match were inscribed.

In the case of league matches (20 games) the referees were examined 75 minutes before the game, while in the case of amateur league matches (11 games) – 30 minutes before the game. The second examination was carried out immediately after the match (amateur matches) or approx. 10–15 minutes after the match (league

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistics of studied group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Age [years]</td>
</tr>
<tr>
<td>Height [cm]</td>
</tr>
<tr>
<td>Body mass [kg]</td>
</tr>
<tr>
<td>BMI</td>
</tr>
<tr>
<td>Referee experience (No. of seasons)</td>
</tr>
</tbody>
</table>

Fig. 3. Primary measurement of side bending

Fig. 4. Actual side bending measurement
matches). The difference resulted from the amount of additional responsibilities the referees had during league matches. The referee is obliged, among other things, to arrive an hour before the match, to verify personal data of the players participating in the game and to participate in a group pre-match conversation. Additionally, after a league match, the referees, together with the qualifier (a person who assesses the referees themselves), assessed the course of the game just played. During the examination, the referee would sit on a chair with a backrest, upright, not leaning against the backrest. Their hands lay freely on the knees bent at right angle. The head was in a neutral position. Male subjects were shirtless, while female subjects wore a sports bra. Both active and passive movements in the cervical spine were measured. Movements in the sagittal plane (bend-extension), in the frontal plane (side bends to the left and to the right) and in the transverse plane (turning the head to the right and to the left) were all measured. The examiner began measurements from marking the topographic points with an “X” made using a coloured pencil. For the flexion movement they were: external tuberosity of the occipital bone and spinous process of C7 vertebra; for extension they were: peak of the chin and the indented part of the manubrium; for side bend of the body: mastoid process of the temporal bone and the top of the acromion. The peak of the chin and the top of acromion were referential points for the turn of the head. Then the researcher measured the distance between the topographic points and put initial measurements for every kind of movement in the right blank (figure 4). The next step was for the subject to perform a given movement (in the case of passive movements the person performed a movement of the head) and then, a re-measurement of distances between referential points was taken (figures 5–7).

In order to reduce measurement error, each measurement after movement was performed 3 times. Every time the measurement was performed by the same person. The result was calculated by subtracting the value of initial measurement from the average measurement of a given movement. Each measurement was put in the study record. Then, the final measurement result was obtained by averaging the particular results. The movements were always examined in the following order: bend, extension, bend and twist of the head, separately for each side of the body. In the aggregate tables, abbreviations are used for particular movements and measurements (Tab. 2).

For statistical analysis, Statistica 10.0 (StatSoft, Inc.) was used. Examination of the significance of differences of dependent variables were performed using Student’s t-test for two dependent tests, while in order to establish

Fig. 5. Measurement of flexion

Fig. 6. Measurement of rotation
Antropomotoryka

the relation between seniority and mobility of the cervical spine, Spearman’s correlation coefficient was used. Results were considered significant at p < 0.05.

Results

The Statistica 10.0 suite was used to calculate the average range of motion of the cervical spine in referees before and after the match. Significant differences concerned the areas of active extension and the active turn of the head before the game (p = 0.040). The average range of active extension before the game was 7.33 cm and 6.89 cm after the match. The average range of active turn of the head to the left was 8.74 cm before the game and 8.20 cm after the match. For the remaining measurements, differences proved to be statistically insignificant (Table. 3).

Also subjected to statistical analysis were the average ranges of right and left bends and average ranges of

Table 2. Abbreviations standing for cervical ROM measurements

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Flexion</td>
</tr>
<tr>
<td>E</td>
<td>Extension</td>
</tr>
<tr>
<td>LSB</td>
<td>Left side bending</td>
</tr>
<tr>
<td>RSB</td>
<td>Right side bending</td>
</tr>
<tr>
<td>LSR</td>
<td>Left side rotation</td>
</tr>
<tr>
<td>RSR</td>
<td>Right side rotation</td>
</tr>
<tr>
<td>PM</td>
<td>Passive movement</td>
</tr>
<tr>
<td>AM</td>
<td>Active movement</td>
</tr>
<tr>
<td>MBG</td>
<td>Measurement before game</td>
</tr>
<tr>
<td>MAG</td>
<td>Measurement after game</td>
</tr>
<tr>
<td>L–R</td>
<td>Difference between measurement for left and right side</td>
</tr>
</tbody>
</table>

Table 3. Mean cervical ROM values in studied referees before and after game (N = 31)

<table>
<thead>
<tr>
<th>Movement</th>
<th>X</th>
<th>SD</th>
<th>MBG–MAG</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_PM_MBG</td>
<td>4.73</td>
<td>1.23</td>
<td>0.31</td>
<td>1.974</td>
<td>0.058NS</td>
</tr>
<tr>
<td>F_PM_MAG</td>
<td>4.42</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E_PM_MBG</td>
<td>7.52</td>
<td>2.09</td>
<td>0.11</td>
<td>0.670</td>
<td>0.508NS</td>
</tr>
<tr>
<td>E_PM_MAG</td>
<td>7.42</td>
<td>1.95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_PM_MBG</td>
<td>5.70</td>
<td>1.34</td>
<td>0.04</td>
<td>0.261</td>
<td>0.796NS</td>
</tr>
<tr>
<td>LSB_PM_MAG</td>
<td>5.67</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSB_PM_MBG</td>
<td>5.13</td>
<td>1.49</td>
<td>0.04</td>
<td>0.284</td>
<td>0.778NS</td>
</tr>
<tr>
<td>RSB_PM_MAG</td>
<td>5.09</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_PM_MBG</td>
<td>9.79</td>
<td>1.35</td>
<td>0.18</td>
<td>0.991</td>
<td>0.330NS</td>
</tr>
<tr>
<td>LSR_PM_MAG</td>
<td>9.61</td>
<td>1.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSR_PM_MBG</td>
<td>9.58</td>
<td>1.18</td>
<td>0.08</td>
<td>0.323</td>
<td>0.749NS</td>
</tr>
<tr>
<td>RSR_PM_MAG</td>
<td>9.49</td>
<td>1.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_AM_MBG</td>
<td>4.01</td>
<td>1.49</td>
<td>0.32</td>
<td>1.886</td>
<td>0.069NS</td>
</tr>
<tr>
<td>F_AM_MAG</td>
<td>3.69</td>
<td>1.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E_AM_MBG</td>
<td>7.33</td>
<td>2.12</td>
<td>0.44</td>
<td>2.147</td>
<td>0.040*</td>
</tr>
<tr>
<td>E_AM_MAG</td>
<td>6.89</td>
<td>2.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_AM_MBG</td>
<td>5.16</td>
<td>1.40</td>
<td>0.15</td>
<td>1.090</td>
<td>0.284NS</td>
</tr>
<tr>
<td>LSB_AM_MAG</td>
<td>5.01</td>
<td>1.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSB_AM_MBG</td>
<td>4.66</td>
<td>1.64</td>
<td>−0.05</td>
<td>−0.315</td>
<td>0.755NS</td>
</tr>
<tr>
<td>RSB_AM_MAG</td>
<td>4.72</td>
<td>1.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_AM_MBG</td>
<td>8.74</td>
<td>1.16</td>
<td>0.53</td>
<td>2.153</td>
<td>0.040*</td>
</tr>
<tr>
<td>LSR_AM_MAG</td>
<td>8.20</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSR_AM_MBG</td>
<td>8.31</td>
<td>1.26</td>
<td>0.24</td>
<td>0.731</td>
<td>0.471NS</td>
</tr>
<tr>
<td>RSR_AM_MAG</td>
<td>8.07</td>
<td>1.17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS – statistically non-significant difference; * – p < 0.05
right and left turns, all before the game (Tab. 4). There is no evidence of statistically significant differences between average range of left and right head turns (both active and passive) in referees working in two-person officiating mechanics. It was demonstrated, however, that there were statistically significant differences between the range of left and right side bends before the game: the average range of passive left bend was 5.70 cm, and the average range of right bend was 5.13 cm (p = 0.006). The average range of movement for active left bend (5.16 cm) also proved to be significantly higher than the average range of the active right bend – 4.66 cm (p = 0.014).

Table 4. Mean range of rotations and side bending to both sides before game

<table>
<thead>
<tr>
<th>Movement</th>
<th>M</th>
<th>SD</th>
<th>L–P</th>
<th>T</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSR_PM_MBG</td>
<td>9.79</td>
<td>1.35</td>
<td>0.21</td>
<td>0.827</td>
<td>0.415*</td>
</tr>
<tr>
<td>RSR_PM_MBG</td>
<td>9.58</td>
<td>1.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_AM_MBG</td>
<td>8.74</td>
<td>1.16</td>
<td>0.43</td>
<td>1.708</td>
<td>0.098**</td>
</tr>
<tr>
<td>RSR_AM_MBG</td>
<td>8.31</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_PM_MBG</td>
<td>5.70</td>
<td>1.34</td>
<td>0.58</td>
<td>2.947</td>
<td>0.006**</td>
</tr>
<tr>
<td>RSB_PM_MBG</td>
<td>5.13</td>
<td>1.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_AM_MBG</td>
<td>5.16</td>
<td>1.40</td>
<td>0.49</td>
<td>2.625</td>
<td>0.014*</td>
</tr>
<tr>
<td>RSB_AM_MBG</td>
<td>4.66</td>
<td>1.64</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS – non-significant difference; * – p < 0.05; ** – p < 0.01

is significant, a difference index was calculated for these ranges. It was calculated for each subject by subtracting the value of the range of movement to the left from the range to the right. Significant differences between the left and right side (before and after the game) concerned the passive side bend. However, a statistically significant difference between the range of active side bend to the right and to the left was noted only before the game (0.49; p = 0.014) (Tab. 5).

To test whether the difference between the range of movement to the left and right before and after the game is significant, a difference index was calculated for these ranges. It was calculated for each subject by subtracting the value of the range of movement to the left from the range to the right. Significant differences between the left and right side (before and after the game) concerned the passive side bend. However, a statistically significant difference between the range of active side bend to the right and to the left was noted only before the game (0.49; p = 0.014) (Tab. 5).

Table 5. Mean range of rotations and side bending to both sides before and after game

<table>
<thead>
<tr>
<th>Movement</th>
<th>(\bar{X})</th>
<th>SD</th>
<th>L–P</th>
<th>T</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSR_PM_MBG</td>
<td>9.79</td>
<td>1.35</td>
<td>0.21</td>
<td>0.827</td>
<td>0.415*</td>
</tr>
<tr>
<td>RSR_PM_MBG</td>
<td>9.58</td>
<td>1.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_PM_MAG</td>
<td>9.61</td>
<td>1.20</td>
<td>0.12</td>
<td>0.55</td>
<td>0.587**</td>
</tr>
<tr>
<td>RSR_PM_MAG</td>
<td>9.49</td>
<td>1.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_AM_MBG</td>
<td>8.74</td>
<td>1.16</td>
<td>0.43</td>
<td>1.708</td>
<td>0.098**</td>
</tr>
<tr>
<td>RSR_AM_MBG</td>
<td>8.31</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR_AM_MAG</td>
<td>8.20</td>
<td>1.5</td>
<td>0.13</td>
<td>0.747</td>
<td>0.461**</td>
</tr>
<tr>
<td>RSR_AM_MAG</td>
<td>8.07</td>
<td>1.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_PM_MBG</td>
<td>5.70</td>
<td>1.34</td>
<td>0.58</td>
<td>2.947</td>
<td>0.006**</td>
</tr>
<tr>
<td>RSB_PM_MBG</td>
<td>5.13</td>
<td>1.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_PM_MAG</td>
<td>5.67</td>
<td>1.37</td>
<td>0.58</td>
<td>2.406</td>
<td>0.022*</td>
</tr>
<tr>
<td>RSB_PM_MAG</td>
<td>5.09</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_AM_MBG</td>
<td>5.16</td>
<td>1.40</td>
<td>0.49</td>
<td>2.625</td>
<td>0.014*</td>
</tr>
<tr>
<td>RSB_AM_MBG</td>
<td>4.66</td>
<td>1.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSB_AM_MAG</td>
<td>5.01</td>
<td>1.36</td>
<td>0.29</td>
<td>1.368</td>
<td>0.181**</td>
</tr>
<tr>
<td>RSB_AM_MAG</td>
<td>4.72</td>
<td>1.63</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS – non-significant difference; * – p < 0.05; ** – p < 0.01
Discussion

So far, no articles have been published covering the examination of the range of movement of the cervical spine in basketball referees, nor has there been such an article for any other sports discipline. The few studies on referees of various disciplines (including basketball) are concerned mainly with psychological aspects of refereeing, or the referees’ physical performance [7–9]. Lark and McCarthy as well as Zietsman and McCarthy studied rugby players from the point of view of the movement of the cervical spine, trying to determine how a single match early in the season affects the movements of the cervical spine. They found that the active range of movement after the game is significantly reduced ($p < 0.05$). In offensive players there is a drop in active flexion, whereas in players in “loose-head prop” and “tight-head prop” positions there is a noticeable decrease in active extension and side bend to the left [10, 11]. In this study, conducted among basketball referees, it was demonstrated that significant differences in the average range of movement before and after the match exist for the active extension and the active left turn of the head. In both cases, the average range of active movement was higher before than after the match. It should be noted when analysing the obtained results that the values of the significance coefficient ($p = 0.04$) are close to being statistically insignificant. Bearing in mind the fact that the sample size is relatively small, the results obtained should be approached with caution. However, both studies on rugby players and basketball referees found that active movements in the cervical spine were reduced after matches. None of the tested range has increased. Moreover, in the present study, examining referees working in two-person mechanics, it was showed that there is a larger range of side bend (active and passive) to the left side than to the right before the game. This may be an outcome of the movement patterns that the referees repeat during the whole match, i.e. “running to counter-attack” (a situation in which a player from the attacking team loses the ball to the defending team, the direction of play changes and the referee must take position on the end line as soon as possible, ahead of all the action) make them twist their head to the left. Additionally, it was found that the difference between the active range of movement to left and right side bends is slightly larger before the match (0.49 cm) than after the match (0.29 cm). Interestingly, for the measurements taken before the match, it was shown that the range of the side bend to the left (5.16 cm) is significantly greater than of the side bend to the right (4.66 cm); the measurements made after the game did not show a similar relationship. The average range of the side bend to the left (5.01 cm) did not differ significantly from the average range of the side bend to the right (4.72 cm). The relationship demonstrated might at first glance suggest that if the difference between the movements to the left and right sides was reduced after the match (from 0.49 cm to 0.29 cm) then there should be an increase in the range of movement to the right (so that the subtracted number was greater). However, previous analyses show that the range of movement of the active side bend to the right before and after the game do not differ significantly. By analysing all the data it can be seen that the drop in the difference to 0.29 occurred with simultaneous slight drop in the average range of side bend to the right (from 5.16 cm before the game to 5.01 cm after it) and a slight increase in the average range of side bend to the left (from 4.66 cm before the game to 4.72 cm after the game). The results should be treated with caution because the

Table 6. The R-Spearman correlation coefficient values between cervical ROM in particular planes and directions and refereeing period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R</th>
<th>p</th>
<th>Parameter</th>
<th>R</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_PM_MBG</td>
<td>0.255</td>
<td>0.173&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>F_PM_MAG</td>
<td>0.391</td>
<td>0.033&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>E_PM_MBG</td>
<td>–0.063</td>
<td>0.740&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>E_PM_MAG</td>
<td>0.018</td>
<td>0.924&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSB_PM_MBG</td>
<td>–0.009</td>
<td>0.961&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>LSB_PM_MAG</td>
<td>0.159</td>
<td>0.403&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>RSB_PM_MBG</td>
<td>0.001</td>
<td>0.996&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>RSB_PM_MAG</td>
<td>0.044</td>
<td>0.819&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSR_PM_MBG</td>
<td>0.137</td>
<td>0.471&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>LSR_PM_MAG</td>
<td>0.191</td>
<td>0.311&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>RSR_PM_MBG</td>
<td>–0.080</td>
<td>0.673&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>RSR_PM_MAG</td>
<td>0.033</td>
<td>0.863&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>F_AM_MBG</td>
<td>0.290</td>
<td>0.120&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>F_AM_MAG</td>
<td>0.337</td>
<td>0.068&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>E_AM_MBG</td>
<td>–0.022</td>
<td>0.907&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>E_AM_MAG</td>
<td>0.011</td>
<td>0.955&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSB_AM_MBG</td>
<td>0.119</td>
<td>0.532&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>LSB_AM_MAG</td>
<td>0.219</td>
<td>0.245&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>RSB_AM_MBG</td>
<td>0.070</td>
<td>0.712&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>RSB_AM_MAG</td>
<td>0.089</td>
<td>0.642&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSR_AM_MBG</td>
<td>0.003</td>
<td>0.988&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>LSR_AM_MAG</td>
<td>–0.082</td>
<td>0.667&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
<tr>
<td>RSR_AM_MBG</td>
<td>0.078</td>
<td>0.684&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>RSR_AM_MAG</td>
<td>0.142</td>
<td>0.456&lt;sup&gt;ns&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

NS – statistically non-significant correlation; * – $p < 0.05$
The influence of two-person officiating on the range of movement... differences, however statistically significant, are relatively small. The question also arises whether the existence of differences of this magnitude may have any significance for the functioning of the referees. In a different study, Lark and McCarty compared the ranges of motion in the cervical spine in rugby players matched for age with people not actively playing. The results showed that the offensive players have values of active movements of the cervical spine similar to people in the acute phase of whiplash. The percentage change in ACROM (Active cervical range of motion) was calculated, between the beginning, the middle and the end of the season, and between the beginning and the end of the season. It turned out that the biggest drop in the values of the ranges of movement in the spine were observed in the second half of the season. The largest relative changes were observed in the side bend to the right, while there were no significant changes in rotation. To sum up, the active range of motion of the cervical spine decreased during the whole rugby season [12].

Research on the referees was carried out in the second half of the season. Not having the test results before the referee season, it cannot be confirmed without doubt that the changes observed in the subjects are larger or smaller compared to the first half of the season.

In the present study, the correlation between the referees' seniority and range of movement in the cervical spine was also examined, and statistically significant results between seniority and passive flexion after the game were achieved. The correlation coefficient $R = 0.39$, $P = 0.033$ indicates that it is a statistically significant correlation with moderate strength. It can therefore be assumed that respondents of longer seniority were characterized by a greater range of motion of passive flexion after the match. Similar conclusions were reached by Lark and McCarty, who compared ROM and proprioception of the cervical spine in rugby players to athletic people not practicing the discipline. The results showed that rugby players had reduced range of movement of the cervical spine when compared to non-rugby players, especially when it comes to extension [13]. This range showed a statistically significant correlation with the number of years of playing rugby. It can be observed, then, that in both studies similar conclusions were reached: playing/refereeing seniority affects the range of motion of the cervical spine, but only in selected directions.

Another aspect that should be taken into consideration is the stress associated with officiating a match. According to Lazarev, refereeing requires enormous concentration and an ability to cope with stress. The stress has its source in the pressure to which referees are exposed, put on them by coaches and players, and fans of both teams. Each of these groups require an fairness and justice in decision-making from the referee. But what for one team will be just a whistle, for the other might be “unfair” [14]. The stress of running a match is different depending on the importance of the match and referee's experience. The higher the “stake”, the greater the stress and the responsibility for a match. An additional reason for severe of anxiety may be that referees are evaluated by a commissioner for their decisions and attitude. A commissioner’s opinion can have impact on whether the referee will advance and will be able to officiate matches in higher leagues. Lundberg et al. examined the effects of stress factors on the activity of the trapezius muscle using EMG. It turned out that solving tests under time pressure increases trapezius muscle activity [15]. A similar pattern was found by Bruno Garza et al., who studied the effect of stressors on the tension of trapezius muscle in people working in front of a computer [16]. It can therefore be expected that in basketball referees, the tension of the trapezius muscle during the game is also increasing due to stress, which may indirectly affect the range of movement of the cervical spine after the match.

An analysis of the collected material confirmed that two-person officiating mechanics affect the range of movement of the cervical spine in basketball referees. It was also confirmed that before the game, there is a larger range of side bend (both active and passive) to the left side compared with the movement to the right. It would seem, however, that in order to verify the results a larger group of respondents should be examined. The present study also managed to partly confirm the relationship between seniority and the range of movement before the game. However, the low sample size does not allow radical conclusions. Results obtained suggest further analyses and further research on more numerous groups, taking into account sub-groups depending on other factors such as the moment during the season in which the movement measurements are made. It is the authors’ opinion that more studies on measurements of range of movement of the cervical spine should be conducted, not only among basketball referees or basketball players, but in athletes and referees of other disciplines as well.

Conclusions

1. Using two-person officiating mechanics has significant impact on the range of movement of the cervical spine in basketball referees.
2. The range of active extension of the cervical spine and an active head turn to the left is larger before the game and reduced after the match.
3. In referees practicing two-person officiating, before the game there is a larger range of side bend (both active and passive) to the left than to the right.
4. Referees with longer seniority show a greater range of movement of passive flexion after the match.
References


Address for correspondence:
Barbara Koperska  
e-mail: koperska.b@gmail.com  
mobile: +48 601 305 458
THE ASSESSMENT OF RANGE OF MOTION IN SELECTED JOINTS IN COMPETITIVE SWIMMERS

Natalia Radlińska¹²³⁴, Arkadiusz Berwecki¹²⁵

Faculty of Movement Rehabilitation, Bronisław Czech University of Physical Education in Krakow

Keywords: swimming, range of motion, hypermobility

Abstract

Background. Differences in range of motion between groups of athletes specialising in various disciplines result from the specificity of these disciplines. Competitive swimmers spend many hours training, which affects motor characteristics, including flexibility.

Objective. To assess the difference in mobility of the joints: upper limb girdle, knee joint and ankle joint between groups of competitive swimmers and people who have never trained swimming or any other disciplines and, also, to determine whether there are any differences in range of motion in these joints between groups of swimmers specialising in various strokes.

Material and methods. 63 individuals aged 17 to 23 participated in the study. The subject group included 32 competitive swimmers (13 women), with at least 5 years of experience in competitive swimming and minimum 10 training units per week. The control group included 31 individuals (14 women) who were not engaged in any sports discipline (did not participate in more than 3 training units per week). Range of motion in the upper limb girdle was assessed using the Bloomfield test. Extension in the knee joint, dorsiflexion and plantar flexion in the ankle were measured using a goniometer. Inversion and eversion of the foot were measured using an instrument designed by authors.

Results. Greater mobility in the upper limb girdle and extension in the knee joint were observed in group of competitive swimmers compared to the control group. Measurement of ankle movement showed that female swimmers had greater dorsiflexion and male swimmers had greater plantar flexion than the controls. Inversion was slightly larger and eversion was smaller in the swimmer group.

Conclusions. Competitive swimmers had greater range of motion in the upper limb girdle and the ankle than the control group. Swimmers are also more likely to have hyperextension in the knee joint. Differences in range of motion between groups of swimmers specialising in various strokes were not noticed.

Introduction

Swimming is a discipline recognized as one of the most beneficially affecting the human body. It is a particularly recommended form of recreation and rehabilitation. The benefits of this form of physical activity mainly result from the specificity of its aquatic environment. Floating in water or performing different strokes requires the involvement of many muscle groups. Overcoming water resistance develops muscle strength and endurance, and improves overall fitness by activating the cardiovascular and respiratory systems. The aquatic environment is used in physiotherapy as a form of relief, especially recommended for joint pain or injuries when one should not be allowed to take on axial loads.

As a sports discipline, swimming requires a lot of effort and dedication. Competitive swimmers at the highest level spend dozens of hours a week in the water. Characteristics of the aquatic environment, techniques of movement in different strokes and multiple repetition of movement patterns require specific shaping of individual motor skills: strength, speed, endurance, co-
ordination and flexibility. The above-mentioned factors affect the range of motion in the joints of people practicing swimming, and as a result, can make it differ from physiological standards.

Biomechanical factors affecting the range of motion in selected joints of swimmers

Swimming is one of the so-called “Overhead sports”, which require repetitive lifting of the arms above one’s head. Tennis, volleyball and all kinds of throwing disciplines also belong to this group of sports. High-level competitive swimmers perform 2,500 cycle repetitions per day in their main stroke. Annually, this number exceeds 500,000. The large range of motion in the shoulder joints required for swimming and the large number of repetitions are the main factors inducing pain associated with the girdle of the upper limbs. Numerous studies show that pain episodes within the shoulder occur in 40-90% of swimmers [1, 2, 3, 4, 5]. The mechanisms of injury in this sport can be different. To a large extent, they depend on the biomechanics of movement, characteristic of each stroke. Often the cause of pain is overloading the muscles, especially the rotator cuff and pectoral muscles. In addition, training focused on strengthening the muscle adductors and rotating internally, can lead to an imbalance of muscle tension. This may result in a reduction of dynamic stabilization of the shoulder joint. Instability, in turn, can cause subluxation and numerous micro-traumas, adding up during multiple repetitions of movements may even lead to labral tear [1].

Another joint susceptible to overloading in swimmers is the knee joint. Competitors specializing in the breaststroke are particularly vulnerable to these ailments. Most often, they complain of pain in the medial knee compartment, which may be associated with specific loads that occur while performing paroxysmal movements in the breaststroke swimming technique. According to studies, 86% of swimmers specializing in the breaststroke had an episode of knee pain at least once. It is reported that the risk of such episodes is five times higher for the breaststroke than other swimming styles [5]. Lopsiding the knee during paroxysmal movements can be the cause of pain on the medial side of the joint. Freestyle, butterfly and backstroke can also cause overburdening of the knee joints. When performing paroxysmal movements, maximum extension of the knee joint occurs, and water resistance forces acting on the limb intensify the extension (Fig. 1, 2).

The muscles straightening the hip joint act on the proximal part of the limb. Water resistance force, which have opposite turn to the force of hip muscles, acts on the entire surface of the limb: thigh, lower leg and foot.

![Fig. 1. Diagram showing the forces acting on the knee while swimming the backstroke and butterfly](image1)

![Fig. 2. Hyper-extension of the knee joint during the crawl stroke](image2)
Resistance forces, acting distally to the knee joint, cause intensification of its extension. Multiple repetition of this movement may cause stretching of structures responsible for stabilizing extension in the joint.

Hyper-mobility of the knee joint can cause symptoms of pain in the back of the joint capsule and reduction of joint stability [6]. In people with hyper-extension, decreased proprioceptive control can be found, particularly in the final phase of the extension. This increases the risk of damage to the knee joint. In the research by J. Loudon et al. [7], it is suggested that patients with increased hyper-extension of the joint are five times more at risk of damage to the anterior cruciate ligament [8, 9]. Ramesh et al., conducted a study on a group of 169 people following ACL reconstruction in one knee. In this research 78.7% of the subjects presented hyper-extension above 10° in both knee joints. In the control group, which consisted of persons not declaring any knee joint pain, hyper-extension was diagnosed in 37% of the patients [10]. Hutchison et al. contend that hyper-extension in the joint leads to incorrect habitual posture because the excessive extension in knee is perceived as normal. Subjects presenting it, tend to take a standing position in which the knee joint is hyper-extended. This can lead to overburdening of the joint, related to non-physiological stance [11]. These reports suggest that hyper-extension of the knee joints increases the risk of both overload and acute injuries. Sudden injury can occur when an additional force acts on this stance, such as a blow, causing an increase in hyper-extension. The muscles are then not able to absorb the forces by increasing the tension or bending the knees quickly enough.

The proper execution of movements in various strokes are also dependent on hocks. Often competitors, especially during the warm-up, perform stretching exercises designed to maintain an adequate or even increase the range of motion in the joints [12]. According to some researchers and trainers, while performing the downward kicking movement during the crawl stroke, the foot should be facing upwards and inwards as much as possible [13]. The forces acting on the ankle joint during movements of the stroke are similar to those acting on the knee joint and can cause a similar phenomenon of stretching certain anatomical structures. In this case, the resulting muscle strength and water resistance contribute to enhancing plantar flexion and inversion in the joint (Fig. 3).

**Study aim**

The aim of the study was to investigate differences in mobility of the following joints: shoulder, knee and ankle, between a group of people professionally-training swimming and untrained persons, as well as to determine whether there are differences in mobility in those joints between swimmers specializing in different styles of swimming (breaststroke, backstroke, freestyle, butterfly). The joints selected for the study were those whose mobility is determined by the correct technique of each swimming stroke: shoulder joints, in which flexibility is particularly exposed in the butterfly stroke, and hocks, determining the effectiveness of footwork in all of the strokes. The mobility of the knee joints was tested for specific loads, to which the limbs are subjected, especially during the butterfly stroke.

**Study material and methods**

The study involved 63 participants who were divided into two groups: those training swimming (51%) and randomly selected untrained (in any discipline) individuals (49%). The inclusion criteria for the study group were among others: minimum 5-years training experience, the number of training units per week – minimum of 10, no injury that may affect the results of range of motion measurements. The study involved 57% men, and 43% women. The study participants ranged in age from 17 to 23 years, mean age = 18.1 years. The individuals training and not training swimming did not differ among themselves in terms of age: t(61) = 0.12; p = 0.906. The average body height of the subjects was 177 cm (155 cm min. and 201 cm max.), their body mass was an average of 69.3 kg (from 43 kg to 93 kg). There were no statistically significant differences between the two analyzed groups in terms of body height: t(61) = 1.37; p = 0.177 or body mass: t(61) = 0.99; p = 0.327. The training experience of the subjects from the studied group ranged from 7 to 15 years, with an average M = 9.5 years.

The dominating styles for 6 of the participants was the breaststroke, for 9 – the butterfly, the backstroke for 10 of them, and 7 specialized in the crawl stroke.
Study methodology

Prior to testing, anthropometric measurements were taken, i.e. body mass, body height and shoulder width (distance acromion-acromion).

For the measurement of range of motion, the following were selected: upper-limb girdle, knee and ankle joints. The upper-limb girdle was examined using a test developed by J. Bloomfield in 1967. The subject moves his/her straightened arms upward in front, then behind his/her back while holding a stick his/her hands. The result of the test is the distance between the subject’s thumbs which are clenched on the stick by their fists. The examiner makes sure motion abduction compensation does not occur during movement and sees to it that the movement was made symmetrically, without bending the elbow joints (Fig. 4).

In order to objectively compare the mobility of the girdle joints (to exclude discrepancy resulting from differences in shoulder width), the “Bark” (=shoulder) indicator was constructed (shoulder width [cm]/mobility of the shoulder [cm]).

Hyper-extension in the knee joint was measured with the Baseline 365° metal goniometer. During the measurement, the subject laid face-up on the couch, the lower legs not touching it. The dorsiflexion plantar ankle movement was examined using the Baseline 365° metal goniometer.

The movement of inversion and eversion was measured using a self-constructed instrument, allowing to read data simultaneously from the two angular planes: transverse (movement around the vertical axis of the device) and the frontal (around the long axis/horizontal). The study was conducted in a lying position, the subject lying on his/her back. (Fig. 5).
The assessment of range of motion in selected joints in competitive swimmers

The lower leg of the subject was stabilized with the immobile parts of the instrument. Then, the subject was instructed to perform a movement of inversion (instruction: “bend the foot maximally towards the floor and turn inwards”) and eversion (instruction: “bend the foot maximally towards yourself and turn outwards as if you are trying to grab your little toe”). After performance of the movement, the examiner applied the movable part of the device to the foot of the subject, so that the line formed by the heads of the metatarsals was parallel to the surface of the board (Figs. 6, 7).

After applying the moving part parallel to the foot, the results were read from protractors. In order to facilitate the comparison of results of inversion and eversion, an index summing up the of angle results from the vertical and horizontal axes for these movements was created.

To ensure the reliability of the measurements, they were taken by one examiner. The mobility in chosen joints was checked after a brief, individual warm-up. The subjects were instructed to make a few movements (5–10 repetitions) in each of the tested joints: swings in the shoulder joint, bending and straightening of the knee joint and abduction of the ankle joint.

Results

Analysis showed that the women training swimming had a larger shoulder width by 3.8 cm ($\alpha < 0.001$) and their mobility was higher by 27.5 cm ($\alpha = 0.001$) compared to women who had no training in this sport (Diag. 1). No statistically significant differences were found between women with different dominant swimming strokes.

![Fig. 6. Eversion measurement](image)

![Fig. 7. Inversion measurement](image)

![Diag. 1. The average level of upper-limb girdle mobility (cm) (lower results indicate better mobility) shoulder width (cm), women.](image)
The same analysis in men showed no differences in shoulder width, however, they were noticeable in mobility: the average in the trained group was about 22.35 cm larger than the untrained ($\alpha = 0.001$) (Tab. 1). No statistically significant differences were found between men performing different dominant swimming strokes.

It was found that women who trained swimming had a higher range of hyper-extension in the knee by 5° ($\alpha = 0.018$), plantar flexion of the hock by about 8° ($\alpha < 0.001$), inversion in the horizontal axis by 7° ($\alpha = 0.035$), but lower levels of eversion in the horizontal axis by 4.6° ($\alpha = 0.035$) compared to women untrained in this sport (Diag. 2). The analysis showed no statistically significant differences between women performing different dominant swimming strokes.

For the men, analysis showed that subjects training swimming had a larger range of knee hyper-extension by 3.8° ($\alpha = 0.006$), range of hock plantar flexion by 11.9° ($\alpha = 0.001$), inversion in the vertical axis by 7.8° ($\alpha = 0.044$) and by 11.4° in the horizontal axis ($\alpha = 0.002$), but a lower eversion level in the horizontal axis by 4.3° compared to men untrained in this sport ($\alpha = 0.002$) (Diag. 3).

In the case of shoulder, inversion and eversion indicators – no statistically significant differences were found among women. However, in the trained men, the inversion indicator was higher by 19.3 ($\alpha = 0.007$), and the shoulder indicator by 0.15 ($\alpha = 0.001$) (Tab. 2).

**Tab. 1.** Descriptive statistics for shoulder width and upper-limb girdle mobility (lower results indicate greater mobility).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Swimming training</th>
<th>Average [°]</th>
<th>Standard deviation</th>
<th>Student’s t-test result</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder width</td>
<td>Yes</td>
<td>43.05</td>
<td>2.17</td>
<td>0.27</td>
<td>0.785</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>42.85</td>
<td>2.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder mobility</td>
<td>Yes</td>
<td>77.00</td>
<td>19.93</td>
<td><strong>3.62</strong></td>
<td><strong>0.001</strong></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>99.35</td>
<td>16.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diag. 2. The average level of individual measurement variables [°] in the studied groups of women
The assessment of range of motion in selected joints in competitive swimmers

Discussion

Swimming is a discipline which strongly shapes all motor characteristics of a competitor. The aim of the study was to evaluate its impact on various ranges of motion in the joints. Research confirms increased mobility of selected joints in swimmers. The reason for this may be genetic predisposition of competitors to greater mobility of the joints. Wanivenhous et al., diagnosed constitutional joints hypermobility for 20% of swimmers [4]. According to various authors, Benign Hypermobility Joint Syndrome (BHJS) occurs in 4–43% of the population. Differences stem from lack of standardized diagnostic criteria, race, sex and age of the subjects [14]. Research conducted by a scientific team from Krakow on a group of 96 girls aged 16–18 years, indicates that BHJS occurs in 28% of subjects diagnosed using the Beighton scale, and 45% when using the Bulbeny scale [15].

In the case of athletes specializing in other disciplines, a series of tests for diagnosing generalized hypermobility of the joints was conducted (Generalized Joint Hypermobility – GJH). This most often affects ballet performers – 97% of them were diagnosed with GJH [16]. Among the professional dancers, hypermobility was diagnosed for 66% of them. Soper et al., diagnosed articular hypermobility and 63% in those practicing netball [17], Decoster et al., 49% in lacrosse players [18] and Stewart and Burden 24% in rugby players [19]. Okamura et al. examined the occurrence of GJH in figure-skaters

Table 2. Descriptive statistics for individual indicators in the studied groups of men

<table>
<thead>
<tr>
<th>Index (width / mobility)</th>
<th>Swimming training</th>
<th>Average [°]</th>
<th>Standard deviation</th>
<th>Student’s t-test result</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>0.59</td>
<td>0.15</td>
<td>3.82</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0.44</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diag. 3. Average level of individual measurement variables in the studied group of men
There are ongoing discussions on BJHS and GJH diagnostic criteria. Dr. Kate Amon in her publication claims that diagnostic tools used to confirm BJHS (i.e. Beighton Score) needs to be improved. In her view, the Beighton Score may mistakenly diagnose BJHS in people who suffer from various types of pain in the musculoskeletal system of different origin [21].

In the case of the upper limb girdle, the appropriate scope of its mobility is necessary in order to effectively perform the technique of movements in different styles so as to minimize friction and increase efficiency of propelling movements [5]. This is probably because, among swimmers at a high level, the percentage of individuals with increased mobility of the shoulder girdle is greater.

From a British study group consisting of 453 children aged 9-18 years training swimming, gymnastics, football and tennis, the swimmers presented the greatest mobility of joints. Particularly large differences were seen in the mobility of the shoulder girdle measured using the “safety pin” test [22]. Our study confirms these results. The “safety pin” test and the Bloomfield test, although differing from each other, measure the global range of motion in the whole shoulder girdle (in the complex planes, in the left and right shoulder joint, simultaneously). For both women and men, the Bloomfield test results indicate greater mobility of the shoulder joint complex in swimmers compared to the untrained group.

The research conducted by Jansson et al. on mobility of joints in children is not so clear. The measurements were taken for 120 swimmers and 1,277 untrained children aged 9 and 12 years old. Using the Beighton on scale, flaccidity of the joints was assessed with the drawer test, the stability of the shoulder joint was examined, and using the so-called Sulcus Test, its lower stability was tested. The internal and external rotation of the shoulder joint was measured goniometrically. The trained boys showed greater joint laxity than those from the control group, whereas the differences between the trained and untrained girls were not significant. Between the groups, there were no differences in the stability of joints in both girls or boys. However, among the young swimmers of both sexes, limitation of internal rotation was found, and for the trained girls, of external rotation as well. The divergence in the results of the study is probably due to the different ages of the subjects. Swedish researchers did not provide training experience or current frequency of training in the study inclusion criteria, which makes it difficult to compare the results [23].

Torres et al. conducted studies comparing internal and external rotation, and so-called GIRD (glenohumeral internal rotation deficit), thus an internal rotation deficit in the shoulder joint of dominant limb in swimmers, tennis players and those untrained. Analysis showed no differences in external rotation between the groups. In contrast, internal rotation proved to be the smallest in tennis players and the largest in the untrained group. Similarly, GIRD: in tennis players, the difference in internal rotation between the non-dominant and dominant limb was 23°, for swimmers 12°, while in the control group, it was 4.9°. Reduction of internal rotation may be the result of a number of overlapping micro-injuries leading to contracture in the rear of the joint capsule. GIRD in tennis players results from the characteristics of the sport – the vast majority of over-the-head movements is performed by the dominant limb. Swimming is a sport in which work is performed by right and left forelimbs equally, yet GIRD may result from greater force applied to the movement of the dominant limb; however, it remains unclear if this is the case [1]. The present study demonstrated that global mobility of the upper limb girdle is greater in swimmers than in untrained people. The Bloomfield test checks the range of circumduction – which is a combination of flexion, abduction and external rotation, and so does not exclude restrictions on internal rotation in swimmers.

The present study showed that the range of extension in the knee joints turned out to be significantly higher in athletes training swimming. The measurements of the movement in swimmers are not very well described in scientific reports. The probable reason for the higher range of extension in the knees are the forces at work during propulsion movements during the freestyle, butterfly and backstroke swimming techniques. The forces broaden the extension of the joint, which extends ligamentous structures responsible for stabilization. Swimmers whose dynamic stabilization of the muscle is well-trained are probably less exposed to the consequences of non-physiological range of extension in the knee joint than people not engaging in physical activity. It is worth noting that the non-contracting structures (subjected to prolonged stress affecting their extension) have limited regenerative capacity (i.e. they regenerate little or not at all) and muscle stabilization regresses rapidly after cessation of exercise. It is therefore possible that the effects of hyperextensions in the knee joint – in the form of various types of overload pain, will be noticed only after cessation of the exercise.

The knee joint is, after the shoulder joint, the most frequent cause of pain for swimmers [4]. The frequency of structural and functional abnormalities in the knee joint is difficult to assess because they are not always associated with pain. The study conducted with magnetic resonance imaging on a group of young, asymptomatic swimmers showed at least one pathological symptom, visible in 69.2% of the swimmers. In the control group, the percentage was 32.1%. The illnesses...
The assessment of range of motion in selected joints in competitive swimmers

most commonly diagnosed with imaging were swelling of the Hoffa body fat and bone bruising within the femoral condyles, tibial plateau and patella [24]. The cause of pain in the front part of the knee joint can be found in patellofemoral joint degeneration, caused by frequent contractions of rectus femoris while performing the freestyle, backstroke or butterfly stroke. On the other hand, breaststroke swimmers complain of pain in the medial side of the knee and their complaints about the knee joint are indeed the most common [4]. Pacey et al. report in their review article that generalized articular hypermobility is linked to knee injuries in athletes of various disciplines [25]. Bin AbdRazak et al., studied people following musculoskeletal injuries. Within this group, those with hypermobility were over three times more numerous than in the control group. Most often, they suffered from knee injuries [26]. The diagnosis of hypermobility it based, among others, on finding increased hyper-extension in the joint (above 10°). The range of movement was proved to be significantly greater in swimmers than in the control group, which may predispose swimmers to more frequent injuries.

The premise to explore the range of mobility of the talocrural and subtalar joints were reports suggesting that the likely range of plantar flexion and inversion affects the effectiveness of swimming. The results of research conducted by McMollough et al. show that swimming speed is only affected by greater plantar flexion and not greater inversion [13].

Another factor that may affect the mobility of these joints are the specific effects of muscle force and water resistance. Just as in the knee, they can affect extension of structures responsible for stabilizing the joint. The results of the present study indicate that the scope of plantar flexion in the talocrural joint is significantly greater in men training swimming than in those who do not train. In swimmers, it is also approx. 65°, while in those untrained 52°. The result does not vary in women – it is approx. 65°. Because women generally have greater joint mobility, it is possible that the range of dorsiflexion motion determines the performance of propulsion. Perhaps optimal mobility, allowing for proper movement techniques is approx. 65° and it does not differ from the physiological mobility in women, while it is optimized in men as a result of training. Similar with inversion – it is higher in trained women, although statistically significant results were found only regarding the horizontal axis of the measuring instrument. The results of vertical and horizontal axes and the summing indicator of both axes were significantly higher in trained men and their values similar to those achieved by women (smaller only by approx. 2°). The range of eversion proved, in turn, to be lower in trained women and men as compared to those not training. Tests of statistical significance indicated only a smaller range of eversion in the horizontal axis as a valuable result, but this may indicate a tendency to limiting the range of this motion in trained men and women.

Comparison of the range of motion in specific joints, performed among swimmers specializing in various styles, showed no significant differences in the measurements. Biomechanics of joint work in during the freestyle, backstroke and butterfly stroke are similar. It is different in the breaststroke, which may suggest some differences in mobility of the joints. The lack of significant differences may result from the small number of subjects. Another reason for the lack of differences may be the effect that during training, swimmers always use strokes other than their primary ones. They use the front crawl especially during endurance preparation, largely because it is the most effective of all strokes in this respect.

The present study has shown that in most cases, swimmers demonstrate greater mobility of the joints than people not associated with this discipline. This is probably the result of long training, heavily influencing swimmers’ organisms. However, since the range of movement affects the quality of swimming, there is a possibility that genetically predisposed individuals with greater mobility of joints, perform better in the sport and continue training at a competitive level.

Conclusions

- People training competitive swimming have greater mobility of the ankle and shoulder joints.
- The occurrence of hyper-extension in the knee joints is more frequent in trained than untrained individuals.
- There are no differences in the mobility of the joints of the swimmers specializing in various swimming strokes.

References


Address for correspondence:
E-mail: radlinska.n@gmail.com
Tel.: +48 538 109 794
IMPACT OF SYSTEMIC CRYOTHERAPY ON SELECTED ENZYMES, GLUTATHIONE AND SERUM TOTAL PROTEIN LEVELS IN HEALTHY YOUNG MALES

Bartłomiej Ptaszek\(^1\) ABDEF, Aneta Teległów\(^3\) ABDEF, Jacek Głodzik \(^3\) BD, Jakub Marchewka \(^4\) CE

\(^1\) Ph.D. student, University of Physical Education in Krakow, Poland  
\(^2\) Malopolska Cryotherapy Centre, Krakow, Poland  
\(^3\) Department of Clinical Rehabilitation, University of Physical Education in Krakow, Poland  
\(^4\) Department of Orthopaedics and Trauma Surgery, 5th Military Hospital, Krakow, Poland

Key words: systemic cryotherapy, enzymes, AChE, G-6-PD, GSH

Abstract

**Study aim.** Determining the impact of systemic cryotherapy on the levels of AChE (acetylcholinesterases), G-6-PD (glucose-6-phosphate dehydrogenases), GSH (glutathione), plasma proteins and occult Hb (occult hemoglobin) in young healthy men.

**Study group.** The study group comprised of the 10 healthy men (untrained) aged 23–24 years (23.4 ± 0.52), who underwent cryotherapy treatments (treatment time 3 min, chamber temperature of –120°C, 10 treatment sessions – 5 times a week). The average body height was 179.2 ± 6.4 cm, weight 79.6 ± 8.8 kg, BMI 23.4 ± 2.6 kg/m\(^2\). In order to analyze the levels of AChE, G-6-PD, GSH, occult hemoglobin and plasma proteins, venous blood was collected from the study participants three times. The first test (control) took place two months before cryotherapy, the second on the day of beginning treatment and the third test after a series of 10 treatments.

**Methodology.** Measurements were taken using the Helios Beta Z OP Spectro-Lab spectrophotometer, the VisionPro 4.10 Thermo Electron UV-Visible Spectroscopy program. To measure the concentration of AChE [U/gHb] and G-6-PD [U/gHb], the method proposed by Beutler (1986) was used. Plasma hemoglobin concentration [g/100 ml] was determined using the method by Chanazin (1989). The concentration of reduced glutathione GSH [mmol/gHb] was determined on the basis of the method developed by Ellman (1970). The Biuret method was used for the determination of total protein [g/l].

**Results.** Analyzing the average values of AChE [U/gHb], G-6-PD [mmol/gHb] and occult Hb. [g/dl] before and after the usage of systemic cryotherapy, no statistically significant differences were found. However, an increase in total protein concentration [g/l] and a decrease in GSH concentration [mmol/gHb] were found in the men who underwent cryotherapy in relation to the measurement taken two months before starting the treatment.

**Conclusions.** Systemic cryotherapy does not cause any side effects in young, healthy men. Regular usage of cryotherapy treatments may affect the levels of enzyme indicators – total protein (concentration increase) and glutathione (concentration reduction) in the blood.

Introduction

The impact of thermal factors on the human body has been studied for many years. Cold therapy is widely used in clinical practice and sports. The great interest in cryotherapy (WBC – Whole Body Cryotherapy) causes the number extremely low temperature treatment centers to constantly increase [1, 2, 3]. The body’s response to cold is based on hormonal changes [4, 5], in the cardiovascular system [6], nervous sys-
tem and muscles [7] and in the immune system [4, 5, 6, 8, 9]. Many studies have shown a relationship between whole-body exposure to extremely low temperatures and changes in the level of selected enzymes and hormones in body fluids [10]. Morphological and biochemical research carried out after application of cryotherapy is indicative of an increase in levels of hemoglobin, leucocytes and blood platelets compared to baseline values. There is also an increase in serum concentrations of epinephrine, norepinephrine, ACTH, cortisol, testosterone (in men), and a reduction of inflammatory parameters such as ESR, Waaler-Rose reaction, seromucoid [10, 11]. Also observed is the beneficial effect of cryotherapy on the cellular immunity of the body by increasing the number of Natural Killer cells [12, 13]. A series of biochemical antioxidant reactions are launched, thanks to which the adverse effect of free radicals are limited [14]. Despite the many possible health benefits posed by cryotherapy, little scientific information is available in literature, and the impact on laboratory results still requires much research. In our earlier study, we studied the effect of WBC on rheological–morphological indicators, in which we demonstrated the positive effects of these treatments [15]. We have decided to extend the determination by additional parameters.

The aim of the study was to determine the effects of systemic cryotherapy on the level of AChE (acetylcholinesterase), G-6-PD (glucose-6-phosphate dehydrogenases), GSH (glutathione), plasma proteins and occult Hb (occult hemoglobin) in young healthy men.

**Study design**

The study group consisted of 10 healthy males – Physiotherapy students of the University School of Physical Education in Krakow (no athletes; preliminary research – without calculation), aged 23–24 (23.4 ± 0.52), who underwent systemic cryotherapy treatments (10 treatments – 5 times a week). Their average body height was 178.9 ± 6.4 cm, weight 79.3 ± 6.8 kg and BMI 23.5 ± 2.4 kg/m². In order to analyze the AChE, G-6-PD, GSH, occult Hb and serum total protein levels, venous blood samples were drawn from the study participants three times. The first study was held two months before cryotherapy (control) – the control group consisted of the same persons who had taken part in the project), the second on the day of beginning treatments and the third test was conducted after a series of 10 treatments.

The parameters obtained in the cryo-chamber:

- aerial temperature: –60°C
- chamber temperature: –120°C

The time of a single treatment session for the group of males was 1.5 min (1st treatment), 3 min (2nd–10th treatment). 3 ml of blood were drawn from the vein inside the elbow from the participants on an empty stomach in the morning, into EDTA tubes. Blood samples were drawn by a qualified nurse under medical supervision, in accordance with the applicable standards of the Pathology of Locomotion Laboratory at the University School of Physical Education in Krakow, where rheological and morphological parameters of the blood were determined. The study was approved by the Bioethics Committee at the Regional Medical Chamber in Krakow.

Measurements were performed using the Helios Beta Z OP Spectro-Lab spectrophotometer, VisionPro 4.10 Thermo Electron UV-Visible Spectroscopy program. To measure the concentration of AChE [U/gHb] and G-6-PD [U/gHb], the method proposed by Beutler (1986) was used. Plasma hemoglobin concentration [g/100 ml] was determined using the method by Chanazin (1989). The concentration of reduced glutathione GSH [mmol/gHb] was determined on the basis of the method developed by Ellman (1970). The Biuret method was used for the determination of total protein [g/l].

**Statistical analysis**

The data is presented as mean and standard deviation (x ± SD) or median and first and third quartile depending on the normality of distribution which was verified using the Shapiro-Wilk test. The differences between the resulting measurements were analyzed by one way repeated measurements analysis of variance (ANOVA). Sphericity was assessed using Mauchly’s test. In the case that the sphericity assumption was not met, the multidimensional test was used (Wilks’ lambda). When the ANOVA parametric assumptions were not met, differences between the measurements were calculated using the Friedman test. Appropriate post-hoc tests were applied to evaluate the differences between particular measurements. The significance level was set at p<0.05. Analyses were performed using Statistica 10 (StatSoft®, USA).

**Results**

Analyzing the average values of AChE [U/gHb], G-6-PD [mmol/gHb] and occult Hb. [g/dl] before and after the usage of systemic cryotherapy, no statistically significant differences were found. However, an increase in total protein concentration [g/l] and a decrease in GSH concentration [mmol/gHb] were found in the men who underwent cryotherapy in relation to the measurement taken two months before starting the treatment (Tab. 1).
Impact of systemic cryotherapy on selected enzymes, glutathione and serum total protein...

Conclusions

Systemic cryotherapy does not cause any side effects in young, healthy men. Regular usage of cryotherapy treatments may affect the levels of enzyme indicators – total protein (concentration increase) and glutathione (concentration reduction) in the blood.

Discussion

The research presented in this article is intended to show changes in the level of acetylcholinesterases, glucose-6-phosphate dehydrogenases, glutathione, occult hemoglobin and plasma proteins in young healthy men undergoing a series of 10 systemic cryotherapy treatments (~120°C). A review of literature shows lack of data on the effects of systemic cryotherapy on the levels of AChE, G-6-PD, GSH, occult Hb. and plasma proteins (especially in humans).

In our research, we have noted an increase in total protein concentration and a reduction in GSH concentration in relation to the measurements made two months before starting the treatment. However, there were no changes in the average values of AChE, G-6-PD or occult Hb.

In literature, there are few studies on the enzymatic properties of blood in cold water. Nonaka et al. (2012) showed an increase of G-6-PD in rats performing exercise, and then floating in cold water (4°C) [20]. In our study, we did not observe any changes in the activity of glucose-6-phosphate dehydrogenase.

Dede et al. (2002) showed that the reduced level of GSH in the blood of rats in a state of hypothermia is accompanied by reduced G-6-PD activity [21].

Puntel et al. (2013) studied rats with ischemia, compared to healthy subjects [22]. Both groups were subjected to cryotherapy (ice packs). In healthy subjects, no changes in GSH levels were observed.

Based on the research, decreased activity of glutathione in men using cryotherapy treatment was noted. Even though Asian and Meral (2007) used a “different kind of cold” and used the animal model (guinea-pigs with short-term hypothermia), they found the same relationship [23].

Pathological processes may be accompanied by both a reduction and increase in GSH concentration in particular tissues. Action aimed at increasing the level of GSH is beneficial in all these disease states, in which a decrease in GSH concentration occurs. However, a decrease in the level of GSH is recommended in tumor cells in order to increase their sensitivity to chemo- as well as radiotherapy, and also in organ transplantation to induce immunosuppression [24].

Research evaluating the effect of systemic cryotherapy in young men was conducted by Lubkowska et al. (2012) [25]. Its objective was to assess the effect of 20 systemic cryotherapy treatments on the antioxidant system. The author noted, inter alia, that only after 10 treatments, there was an increase in the total protein concentration. The same relationship was observed in the present study. The level of glutathione, however, increased after 10 treatments, and after 20 treatments, decreased compared to the level prior to WBC. In the conducted study, the opposite relationship was observed after 10 treatments.

The conducted research require extension to gain a better knowledge of the body’s response in these conditions. Due to the small size of the study group, this research can be regarded as preliminary. The results of the studies carried out so far (very few) are difficult to interpret and compare because of differences in their research protocols. Lubkowska and Szyguła (2010) showed that the number of WBC sessions is of significance when considering the changes in morphological indicators [26].

In summary, these studies have reported that exposure to cold in the form of systemic cryotherapy can modulate the enzymatic parameters of the blood. It is believed that these results are important in determining the safety of WBC in the field of clinical trials.

Table 1. Mean values ± standard deviation or median and (I-III quartile) of selected serum parameters in males before and after systemic cryotherapy

<table>
<thead>
<tr>
<th>Cryotherapy Measurement</th>
<th>(n = 10)</th>
<th>Measurement 2</th>
<th>Measurement 3</th>
<th>p</th>
<th>p1/2</th>
<th>p1/3</th>
<th>p2/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum total protein [g/l]</td>
<td>65.71 ± 4.66</td>
<td>68.52 ± 8.45</td>
<td>72.71 ± 6.62</td>
<td>0.013</td>
<td>0.381</td>
<td>0.038</td>
<td>0.198</td>
</tr>
<tr>
<td>AChE [U/gHb]</td>
<td>32.58 ± 3.51</td>
<td>30.39 ± 3.35</td>
<td>32.71 ± 4.76</td>
<td>0.350</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G6PD [U/gHb]</td>
<td>0.41 ± 0.09</td>
<td>0.43 ± 0.14</td>
<td>0.47 ± 0.10</td>
<td>0.626</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSH [µmol/gHb]</td>
<td>15.23 (13.17–16.89)</td>
<td>13.68 (13.45–14.53)</td>
<td>10.73 (5.65–12.00)</td>
<td>0.045</td>
<td>0.316</td>
<td>0.039</td>
<td>0.358</td>
</tr>
<tr>
<td>Occult Hb [g/dl]</td>
<td>0.000 (0.000–0.000)</td>
<td>0.005 (0.000–0.010)</td>
<td>0.000 (0.000–0.000)</td>
<td>0.156</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Description: measurement 1 – two months before cryotherapy (control); measurement 2 – day of beginning cryotherapy; measurement 3 – after a series of 10 treatments.
Literature


Corresponding author:
Bartłomiej Ptaszek
E-mail: bartlomiejptaszek1007@gmail.com