

University School of Physical Education in Wrocław
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HUMAN



MOVEMENT

formerly

Człowiek i Ruch (Human Movement)

vol. 9, number 2, 2008

HUMAN MOVEMENT

formerly Człowiek i Ruch (Human Movement)
vol. 9, number 2, 2008, pp. 89–156

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Indexed in: SPORTDiscus, Index Copernicus, Altis, Sponet, Scopus

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ISSN 1732-3991

http://www.awf.wroc.pl/hum_mov

Editorial Office

Secretary: Dominika Niedźwiedź

51-684 Wrocław, ul. Mickiewicza 98, Poland, tel. 071 347 30 51

hum_mov@awf.wroc.pl

Print: Agencja Reklamowa i Drukarnia KONTRA

Circulation: 150



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EDITORIAL

The current issue of *Human Movement* concludes the ninth year of the journal's publication. At present our journal is valued at 4 points on the publication list of the Polish Ministry of Science and Higher Education. From 2009 *Human Movement* will be published on a quarterly basis, which along with the growing number of citations will allow the Editors to apply for a higher point status on the list.

The introductory article is a review paper by A. Wit and A. Czaplicki "Inverse dynamics and artificial neural network applications in gait analysis of the disabled subjects". The majority of papers in the present volume are works on biomechanics, originally delivered at the International Congress of the Polish Society of Biomechanics organized by the University School of Physical Education in Wrocław, from 31st of August to 3rd of September. Among invited speakers were many well known specialists: Michael A. Adams, József Tihanyi, Alex Stacoff, Zeewi Dvir, Ian Sutherland. Papers presented during the congress, after reviews, was published in *Human Movement* journal.

We strongly encourage organizers of conferences and congresses, especially those held in English, to contribute to our journal.

We would like to express our deepest gratitude to all Reviewers for their most effective contribution to the improvement of the quality of *Human Movement* in 2008:

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INVERSE DYNAMICS AND ARTIFICIAL NEURAL NETWORK APPLICATIONS IN GAIT ANALYSIS OF THE DISABLED SUBJECTS*

DOI: 10.2478/v10038-008-0010-y

Andrzej Wit^{1,2**}, Adam Czaplicki³

¹ Faculty of Rehabilitation, Józef Piłsudski University of Physical Education, Warsaw, Poland

² Faculty of Physiotherapy, ALMAMER, Warsaw, Poland

³ External Faculty of Physical Education in Biała Podlaska, Józef Piłsudski University of Physical Education, Warsaw, Poland

ABSTRACT

The aim of this study is to review the achievements of the mathematical modeling of muscles force contribution during walking. In order to determine the contributions of individual muscles to the net force or net muscle torque at a given joint, the external forces acting on lower extremity joints during gait ought to be identified. The solution of this problem, called in biomechanics the inverse dynamics, is now regarded as a classical method of movement modelling. In the hypothesis put forward in this paper, it is considered if the artificial neural network method could be applied to the muscle contraction prediction during gait analysis in normal and disabled subjects. Artificial neural network (ANN) is an artificial intelligence method used in mathematical modelling and its applications in diverse areas, especially in biology and medicine, are steadily progressing. The achievements and possibilities of ANN in biomechanics were presented previously by others authors. For example, Liu and Lockhart [13] attempted at creating a network capable of reproducing muscle forces during gait from EMG signals recorded in working muscles. The objective of our study was to make use of the experience gained in the construction of ANN and to apply advanced mathematical procedures to identical experimental conditions of gait analysis.

Key words: inverse dynamics, artificial neural networks, gait analysis

Introduction

Gait is the principal mode of human locomotion. Having in mind that the lower extremity and trunk joints enable only the rotatory motions, the gait kinematics is a complex phenomenon. Moreover, gait as the principal mode of locomotion, poses high demands on the control system; a small surface of support, high position of the centre of gravity, uneven distribution of mass, domination of heavy segments in the upper part of the body and a high number of degrees of freedom of the entire system, are among the unfavourable features of the human locomotor system control. It ought to be also mentioned that no clear principles of the phylogenetic shaping of the organisation of joints, bones, ligaments and muscles have been found so far. The criteria of motor control involving that many degrees of free-

dom and redundancy of muscle drives have not been identified either. Thus, according to Winter [1], "The fact that we as humans are bipeds and locomote over the ground with one foot in contact (walking), no feet in contact (running) or both feet in contact (standing) creates a major challenge to our balance control system".

Among the principal issues of biomechanics, scrutinized in recent years by many researchers, the effects of forces generated by individual muscle groups on the movements of specific body segments during gait are of great importance. Research in that area focuses predominantly on subjects fit psychophysically; in recent years, however, subjects with locomotor disabilities have gained marked attention in that respect.

Measuring forces at lower extremity joints during gait

Considering the human anatomy and principles of locomotor control, skeletal muscles are the only power drive of body motions. Contracting muscles produce forces acting on bone elements, to which those muscles

*The study was supported by the Polish Ministry of Science and Higher Education grant No. N N404 3302 33.

**Corresponding author.

are attached via tendons. Determining the magnitudes and vectors of muscle forces in relation to lower extremity joints, combined with the ability of making use of them, is the key factor in gait analysis in the disabled subjects. However, in order to determine the contributions of individual muscles to the net force or net muscle torque at a given joint, the external forces acting on lower extremity joints during gait should be identified.

The solution of this problem, called in biomechanics the inverse dynamics, is now regarded as a classical method of movement modelling. Computational procedures used in the two approaches to computer simulation [2], i.e. forward dynamics and inverse dynamics, are presented in Fig. 1. Two elements in this figure are worth emphasizing: solving the inverse dynamics requires that the input should contain time functions of linear $[x(t)]$ and or angular $[\alpha(t)]$ coordinates, as well as those of the first and second derivatives; time function of external forces $[F(t)]$ represents a possible additional input to the model.

Many researchers who employ computer simulation in biomechanics consider Paul's paper [3] as fundamental and opening new methodological perspectives in analytical biomechanics. The author adopted a four-element model consisting of articulated rigid elements.

Other authors [4–10] increased the number of elements or expanded mathematical procedures.

The next step in modelling gait dynamics consisted in supplementing rigid elements with the soft tissue ones. The rigid model did not include muscles, ligaments, tendons, fat tissue, skin, interstitial fluids, etc. The viscoelastic properties of those structures imply an oversimplification of a fully rigid model.

Gruber and co-workers [11] supplemented the “ideally rigid” model with elastic elements representing the soft tissues. That model, presented in Fig. 2, has been widely accepted as the “wobbling mass model” and uses the following equations for rigid and wobbling elements:

	Rigid elements	Wobbling masses
Linear motion:	$m_r \cdot r_r = [\sum(F_{ik} + F_{ic} + F_{id}) + m_{ir} \cdot g]$	$m_w \cdot r_w = -F_c - F_d + m_{ig} + g$
Rotation:	$I_r \cdot \varphi_r = [(\sum F_i \cdot r_i) + \sum M_i + M_c + M_d]$	$I_w \cdot \varphi_w = [-M_c - M_d]_z$
For coupling torques:		
	$T_{wi} = a\Delta\varphi_i + b\Delta\dot{\varphi}_i$	
	$F_{wi} = [c \cdot \text{sign}(\Delta r_{il}) / \Delta r_{il}^3 + d\Delta r_{il}]A_i$	

Surprisingly, momentary forces obtained by both models in e.g. hip joint may differ as much as 8-fold. Remembering, however, that the momentary peak force occurs in the phase of the foot–ground contact and, when the model does not include damping present in

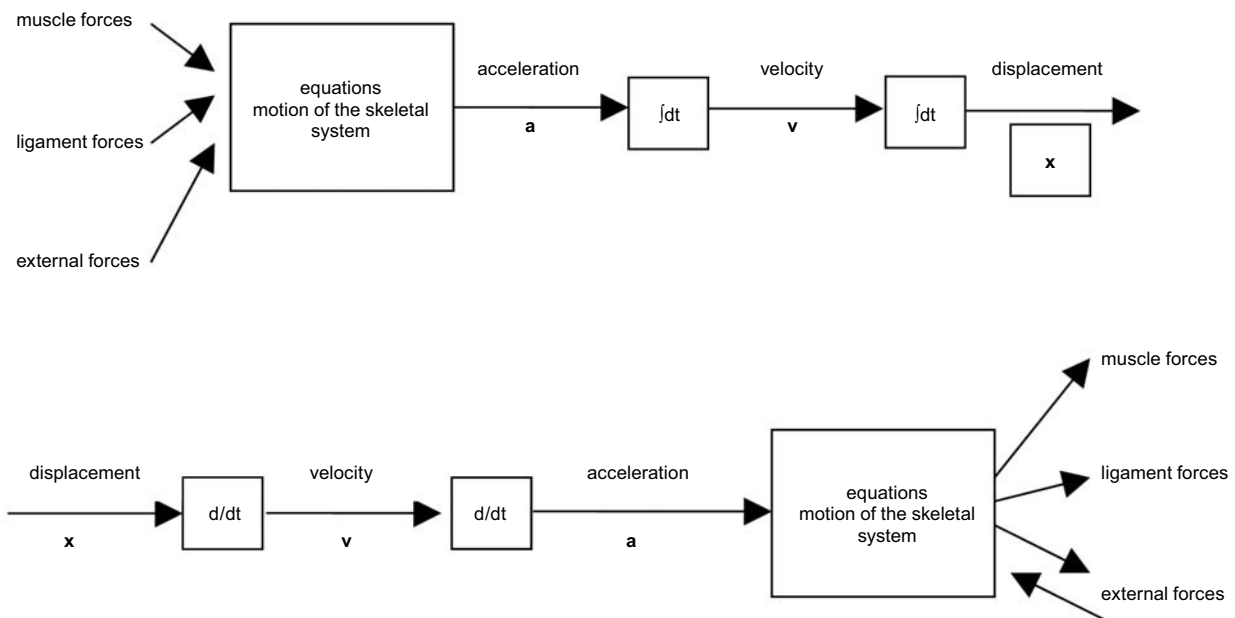


Figure 1. Schematic illustration of the similarities between the process of simulation and inverse dynamics analysis (redrawn from [2])

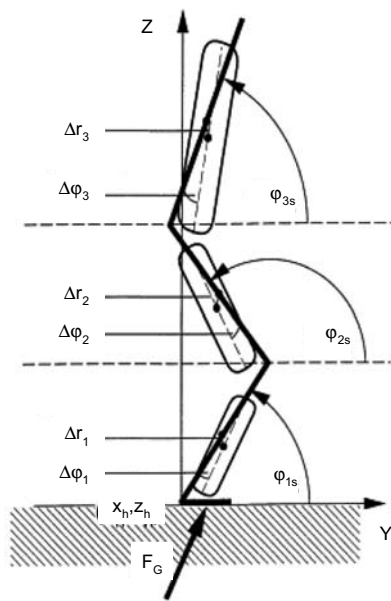


Figure 2. The three-linked model with wobbling mass [11]

a real object, the above-mentioned difference in results is the effect of an oversimplified model.

A fair agreement of the recently reported results was due to an improved modelling of global muscle torques generated in lower extremity joints during gait [12–14]. It may thus be assumed that the curves presented in Fig. 3 adequately represent real gait-related changes in muscle torques [13].

The results of computer simulations of the inverse dynamics issues reported by the above-mentioned authors are not, however, identical despite a high similarity of global changes in lower extremity muscle torques with respect to the direction and tendencies of those changes. The differences in those results may be due to uneven reliability of data input into the model. The variables used to construct models may be classified as follows:

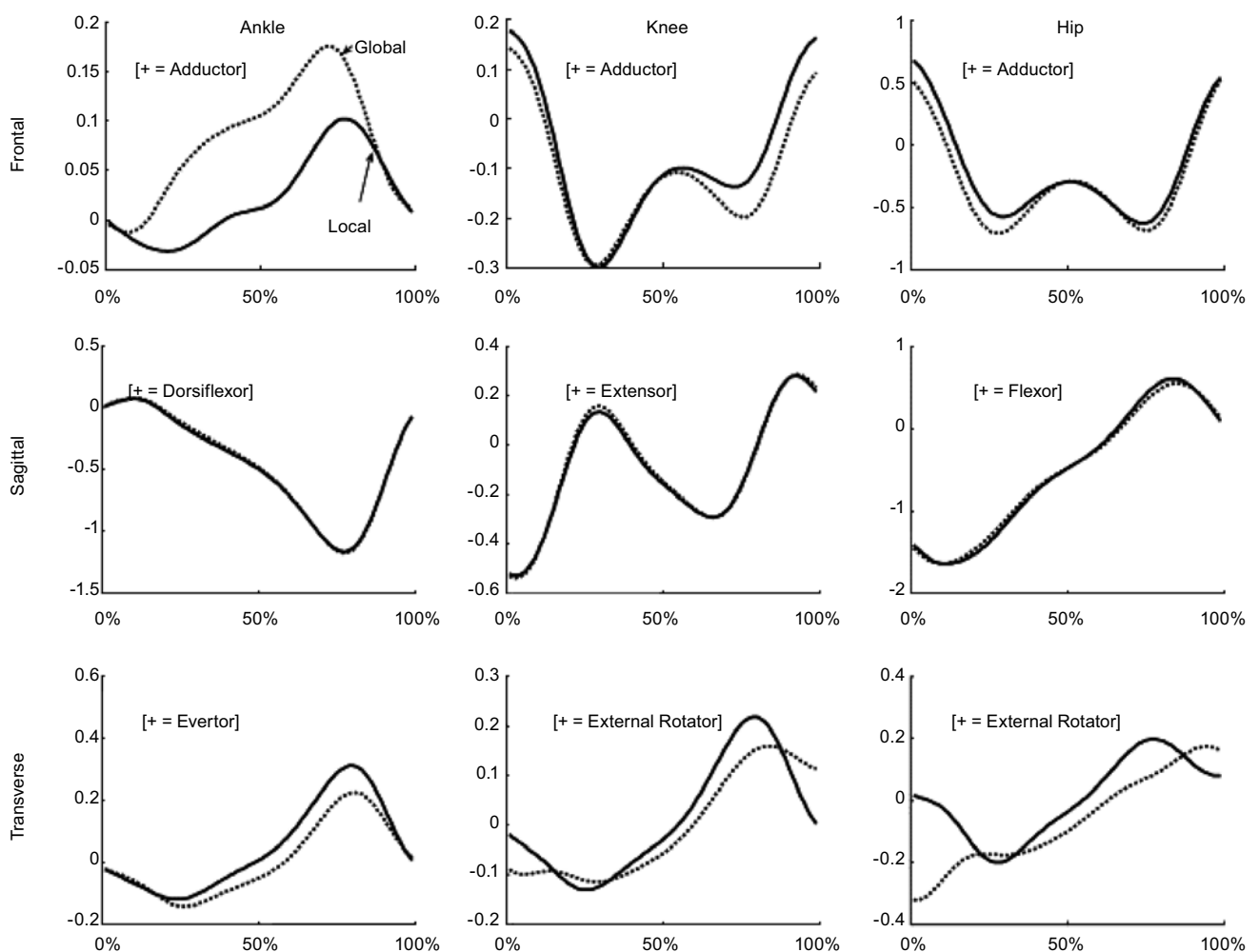


Figure 3. Normalized joint moments (N m/kg) about ankle, knee and hip in frontal, sagittal and transverse planes under global and local coordinates. X-axis represents relative time, with 0% indicating heel contact and 100% indicating toe-off. The curves represent averaged global joint moments (—) and averaged local joint moments [13]

1. Reliable and easily attainable,
2. Reliable but attainable only by employing sophisticated methods (e.g. ground force components),
3. Unattainable intravitally,
4. Non-measurable, due to the fact of being insufficiently defined.

The values of variables from the last two categories are usually obtained post-mortem or assessed by the trial-and-error approach. The forces generated by individual muscles during gait are necessary in modelling but impossible, so far, to be measured directly.

Determining forces generated during gait by individual muscles of lower extremities

Static optimisation is among the most popular methods of determining forces generated by individual muscles in diverse motor activities. The first stage of this method consists in solving the problem of inverse dynamics for discrete values of time, usually equal to the frequency of data recording. The next step is the partition of global muscle torques into individual muscles at consecutive moments of time by employing procedures leading to extreme values of appropriately defined object functions of the process under study. A comprehensive overview of the most popular object functions and of numerical procedures suitable for static optimisation was presented by Tsirakos et al. [15]. A high numerical stability of algorithms, simple course and short computational time, especially for two-dimensional models, are the prime advantages of static optimisation. Computing the time courses of forces of 8 muscles in a planar three-component model of lower extremity in a single gait cycle took only 5.3 s [16], and force characteristics of 9 muscles executing leg swing took 7.2 s each [17]. Stable time courses of all muscle forces were obtained in complex three-dimensional models consisting of as many as 47 or 43 muscles [18, 19].

The principal drawback of static optimisation is the presumed optimal exertion of muscles at every moment of a given motor task; that presumption may greatly affect the results and is difficult to be experimentally verified. In effect, the obtained discrete characteristics of muscle force may not correspond to its real course. Yet, static optimisation was demonstrated to be a valid and reliable tool in studying gait [20].

Contributions of individual muscles to the global force of various muscle groups may also be determined from EMG signals [7, 21, 22] but the respective biome-

chanical models of gait are not popular due to serious errors associated with force assessment in that way, especially in the phase of signal recording. Namely, superficial EMG does not enable recording signals from all individual muscles involved in the motor act; moreover, active muscle fibres located under the muscle examined distort the specific signal.

Possible use in implanted electrodes poses great difficulties and as a routine practice would be rather unreasonable as the access to all muscles engaged may not appear feasible. The lack of experimental data which might reveal the relations between EMG signal variables and changes in muscle force under dynamic conditions, i.e. muscle-driven movements of lower extremities, is another drawback in the application of EMG to determining forces generated by muscles during gait. On the other hand, changes in EMG amplitudes were linearly correlated with muscle force in isometric contraction (static conditions) in the range of 40 to 80% MVC.

EMG records are thus mostly used to verify the reliability of numerical gait simulations [20, 22–24]. The latter authors designed a human musculoskeletal model by using SIMM (Software for Interactive Musculoskeletal Modeling; MusculoGraphics, Inc., USA) package and demonstrated that multijoint muscles – knee and hip extensors – are essential in maintaining body stability in the initial, single support phase of gait. Moreover, the re-distribution of muscle power in the entire gait cycle enabled trunk and lower limb motions. The intuitive obviousness of results confirms the usefulness of the software and of the numerical procedures employed.

Nevertheless, many authors continue the analytical approach to assess the contributions of individual muscles to the global strength. The approaches include the input of measurable variables like: (1) global muscle torque of a single muscle group under static conditions; (2) muscle lengths measured anthropometrically; (3) muscle cross-sections determined ultrasonographically; (4) moments of inertia of segments by applying forced vibration, and (5) experimental data of rigidity and damping. However, the input of the following variables into the model remains unsolved: (1) stresses transmitted by individual muscles; (2) rigidity of the anatomical muscle–ligament interface; (3) activation, i.e. the function of muscle stimulation, and (4) criteria of optimum control of muscle work and of the whole body movements. An advanced simulation procedure was present-

ed by Anderson and Pandy [25] or Pandy and Zajac [23]. The authors started with simulation and performed analytically a dynamic optimisation solution. Next, they collected some data recorded in corpses, in several subjects, as well as data from earlier publications on strength–speed relationships in selected muscle groups, they simulated the contributions of individual muscles to the ground reaction forces and accelerations of individual body segments. The results, which seemed to be close to the real ones, enabled analysing the contributions and significance of those segments in maintaining equilibrium in the support phase and in forward driving the body during gait.

Both papers mentioned above demonstrated the way to compute forces of individual muscles by applying forward dynamic simulation, but employing different numerical approaches. The first approach, a continuation of their earlier report [26], was based formally on the optimal control theory (Pontryagin's principle); the

authors maximised the Hamiltonian function and solved the resulting boundary problem by integrating status variables and conjugated variables in opposite directions. By assuming a linear relationship between muscle activation and its stimulation, a bang-bang control, represented by stimulation, was obtained. Despite the physiological correctness of that solution, the method has been rarely used in biomechanics due to unstable integration of conjugated variables [27], difficulties in physical interpretation of variables and a likely appearance of singular control.

The other approach, first described by Pandy, Anderson et al. [28], avoided the need of solving the boundary problem by transforming the optimal control into parameter optimising problem. The control, expressed also by muscle stimulation, was spread over a net of nodal points, uniformly distributed over time, and forming a discrete set of independent variables subject to optimisation. In that way, the issue was reduced to seeking nodal control values which minimise the integral quality index defined for a given motor task and, at the same time, maintain the constraints forced by the state equations containing the co-ordinates and generalised velocities, muscle forces and muscle activation levels as dependent on their stimulation. These equations were integrated conventionally by using the Runge-Kutta algorithm and the optimal values of control variables were obtained by sequential quadratic programming (SQP). The common use of parametric optimisation greatly reduces the computation time which is a derivative of integrating state equations at every step of the iterative SQP. The computations of two-dimensional models by using a PC take up to several days [29], and up to several months in the case of complex three-dimensional models [24].

A hybrid solution, which combines the features of direct and inverse dynamics, was presented by Menegaldo, Fleury et al. [30]. The first step was the inverse dynamics solution followed by defining a function of errors between the computed global muscle torques at given joints and their optimised equivalents resulting from muscle forces. That function was attached to the integral quality index of the process. Optimisation was conducted by SQP, maintaining the differential constraints describing the contraction and activation dynamics. A substantial reduction of computation time was achieved by eliminating the co-ordinates and generalised velocities from the state vector. Inasmuch highly promising, the arbitrary weights attributed to the

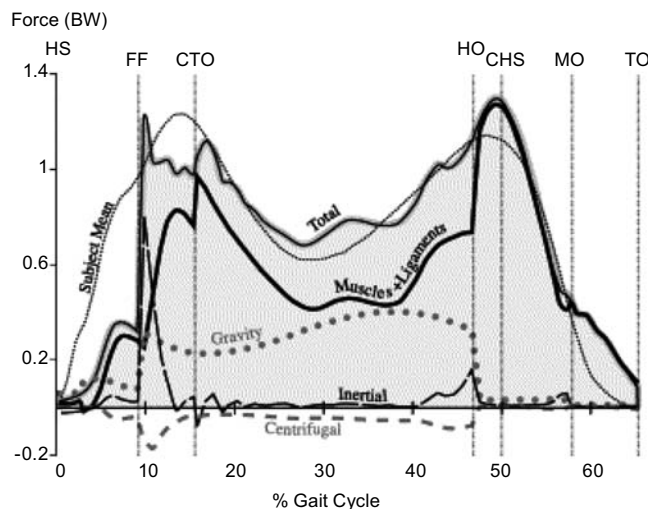


Figure 4. Contributions of inertial forces (Inertial), of centrifugal forces (Centrifugal), of the resistance to gravity provided by the bones and joints of the skeleton (Gravity), and of muscle and ligament forces (Muscles + Ligaments) to support during normal gait. The thick gray line is the vertical ground-reaction force obtained from the dynamic optimisation solution for gait. Total (thin black line) was obtained by summing Inertia, Centrifugal, Gravity and Muscles + Ligaments. The mean vertical ground-reaction force measured for the subjects are shown as a dotted line (Subject Mean). The marked kinematic events are: HS – heel-strike, FF – foot-flat, CTO – contralateral toe-off, HO – heel-off, CHS – contralateral heel-strike, MO – metatarsal-off, and TO – toe-off. BW is body weight (BW = 696 N for the model and the subject mean) [25]

two components of the quality index represent some weakness of the approach.

Ackermann and Schiehlen [16] presented a novel procedure of determining forces for individual muscles based on the inverse dynamics solution and called it the 'extended inverse dynamics'. They modified the classical procedure by including force dynamics and muscle activation, as well as an integral quality index for the entire motor task. Parametric values of muscle forces were taken as optimised variables and an algorithm of sequential programming was used in optimisation. Since the quality index was related to the activation and stimulation of the muscles, time functions of these variables constituted an integral part of computations. The first function was obtained by solving the force–length–velocity relationship for the contractile elements of the muscle preceded by numerical differentiation of muscle force by time, and the other one resulted from differential relationship between activation and stimulation preceded by differentiation by activation time. That method, free of the drawbacks of the classical inverse dynamics, proved more efficient numerically compared with parametric optimisation based on simple simulation. The time needed to generate functions of muscle forces over a single gait cycle for a planar model of lower extremity including 8 muscles amounted to about 12 h [16]. Solving an identical task for leg swing with the use of a planar model which included 9 muscles took over 2 h [31] but in this case a much simpler quality index was used.

A highly advanced software for analysing muscle force (SIMM; Software for Interactive Musculoskeletal Modelling) was designed by Loan, Delp, Smith, Blaike and Megelan (MusculoGraphics Inc., USA) with a significant contribution of van der Helm. The model utilised data from numerous publications and probably also the author's own data. Gait simulation based on ground force values was conducted by the Laboratory for Functional Anatomy, Biomechanics and Motor Control in Copenhagen (Denmark). An example graph of knee joint muscle torques as functions of knee joint angle during gait is presented in Fig. 5. Inasmuch some doubts exist as to whether the author did not manually adjust the force curves as functions of the joint angle so as to obtain a satisfactory concordance with the resultant global muscle force at the hip, knee and ankle joints, the software and gait model, as well as other products offered by the MusculoGraphics, enable diverse simulations, e.g. of changes in muscle length, stress in bones, etc.

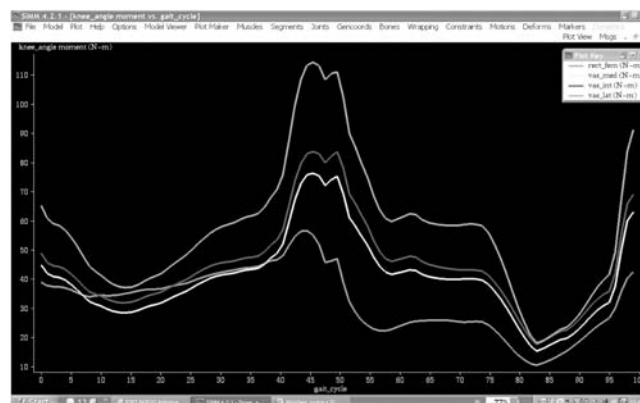


Figure 5. Muscles torque changes of the selected knee extensors during normal walking. Simulation was provided by SIMM

Clinical examples of the effects of force reduction of selected muscle groups on the gait mechanics elements

Bennett, Ogonda et al. [32] analysed the effects of two kinds of hip joint surgery – minimally invasive and conventional, by employing variables of gait kinematics, i.e. downward pelvis displacement during gait; adduction/abduction, flexion/extension and rotation at the hip joint; flexion/extension at the knee joint; foot adduction/abduction; flexion/extension at the ankle joint. Gait velocity, step length, double step length and the duration of the foot–ground contact in the support phase did not differ significantly in both groups on the 2nd day or 6 weeks post-surgery, while rotation at the hip joint differed significantly between groups as well as from the normal values.

Similar values of gait velocity, step length and support duration were noted in women suffering from myofibrosis [33] and ground reaction forces in those women and the control ones were alike. The authors concluded that the pattern of recruitment of lower extremity muscles in myofibrotic women differs from that in healthy subjects; specifically, plantar flexion in myofibrotic women requires a markedly greater muscle work than in the healthy ones, which makes walking very fatiguing.

A similar study was conducted in children with cerebral palsy and, thus, crouch gait [34]. That kind of gait is due to abnormally short hamstring or the *semimembranosus* muscle spasm. The authors recorded changes in muscle length and simulated its shortening rate; they

demonstrated that those children subjected to hamstring elongation who made no use of elongation and, thus, of generating higher forces by that muscle and did not improve the gait-induced shortening rate, were incapable of improving their gait quality. The authors identified the criteria of selecting children who may significantly improve their gait post-surgery. In another study, Goldberg, Öunpuu et al. [35] studied gait in children with cerebral palsy, aged 10 ± 2.8 years, subjected to transplantation and elongation of the *rectus femoris* muscle tendon, elongation of the *gracilis* and *gastrocnemius* muscles, de-rotational osteotomy and corrective foot surgery. The analysis of gait dynamics revealed an improvement in the vertical component of ground reaction force and in the motion range in leg swing. The authors showed that anatomical correction of the *rectus femoris* muscle significantly improved the single support phase, stabilised the gait and made it more efficient. Moreover, they showed that the excessive knee contracture in the support phase was due not only to a functional insufficiency of the *rectus femoris* muscle but also to a contracture and low strength of the *gastrocnemius* muscle. Since not all the children exhibited a post-surgical improvement, the question as to whether the transfer of the *rectus femoris* muscle is the only factor that might improve the stiff knee in children with cerebral palsy, remained unanswered.

Wu, Su et al. [36] presented a mathematically more advanced approach to gait analysis following ankle arthrodesis. A three-component foot model was assumed and 11 markers were used to delimit the components. A kinematographic recording was conducted together with recording ground reaction forces and EMG signals from 5 lower extremity muscles. As compared with healthy subjects, patients with ankle arthrodesis had significantly smaller motion range of the distal part of the foot, greater mobility of the frontal part of the foot in the sagittal and transversal planes, a generally greater stiffness of the distal part of the foot combined with a greater engagement of foot muscles and a decreased EMG activity of large muscle groups, e.g. *rectus femoris* or *soleus* muscles.

Gait kinetics and kinematics was also reported for other diseases, e.g. parkinsonism [37]. Inasmuch the advancement of the disease determines the magnitudes of changes, the general characteristics of gait mechanics are disease-specific. Similar findings were reported for subjects with a shorter [38] or amputated [39] lower limb.

Determining forces generated during gait by individual muscles of lower extremities by using artificial neural network modelling and simulation

Artificial neural network (ANN) is an artificial intelligence method used in mathematical modelling and its applications in diverse areas, especially in biology and medicine, are steadily progressing. The achievements and possibilities of ANN in biomechanics were presented e.g. by Simon [40], who discussed the status of studies on gait biomechanics and pointed to advantages of gait analysis for clinical purposes, as well as to persisting limitations of ANN. Simon's conclusions confirm and support an earlier review on ANN applications to gait analysis [41] and seem reasonable in view of recent reports [42, 43]. Lees [44] reviewed world tendencies in applications of biomechanics to the analysis of movements in sports and emphasised the role of ANN. Worth mentioning are also applications of ANN to the functional electrostimulation supporting the gait in patients with parapareses [45, 46].

Apart from the use of ANN in general gait analysis, like gait velocity or step frequency [47], distribution of forces generated by foot pressure on the ground [48] or ground reactive force [49], in the available literature there were found six reports pertaining to the use of ANN in computer simulation and modelling muscle work during gait. Specifically, the authors discussed the modelling of muscle activity as a basis of modelling changes in kinematic gait parameters [50, 51], modelling muscle work of lower extremities by using kinematic and kinetic parameters [52, 53], or assessing muscle strength from EMG signals [13, 54].

Sepulveda, Wells et al. [50] presented a different approach to the construction of models; they recorded EMG potentials from 16 muscles during a walk at natural velocity together with muscle torques and changes in angles at the hip, knee and ankle joints. They designed a network which represented relationships, although not quite accurately, between the changes in activities of muscles and the movements of lower extremities. They observed the effects of reducing the stimulation of the *soleus* muscle by 30% and of the total exclusion of the *rectus femoris* muscle. Best results were obtained by relating in ANN the EMG signals with muscle torques.

Tucker and White [51] studied changes in the tonus of five muscles in relation to the gait velocity and step frequency. Muscle activity was determined by EMG and kinematic variables on a mechanical treadmill. Hel-

ler, Veltink et al. [52] designed a network fed by time functions of changes in hip and knee joint angles, angular velocities and accelerations, and durations of the contacts of feet with the ground, and the network generated EMG values for the *semitendinosus* muscle. The network could reproduce muscle activities and changes in kinematic variables in cyclical movements performed in six consecutive steps at various velocities.

A more advanced network was presented by Prentice, Patla et al. [53]. They fed the following data: step frequency, lengths of individual steps, durations of support and of extremity swings. Twelve gait forms were studied on a track equipped with obstacles forcing the subjects to walk with varying velocity, step length and knee lifting height. All those variables were input into the network, while EMG variables of eight muscles (*gastrocnemius medialis*, *soleus*, *tibialis anterior*, *peroneus longus*, *biceps femoris*, *rectus femoris*, *gluteus medius*, *erector spini*) during gait constituted the output. The simulated activities of individual muscles were highly satisfactory and the network was capable of reproducing the real activity patterns of all eight muscles throughout the double step cycle. Inasmuch momentary EMG values differed up to 25% in 25 out of 96 combinations of muscles and gait forms, it could be concluded that ANN proved a reliable tool in the modelling and simulation of muscle work based on principal variables of gait kinematics.

EMG signals were also used to assess the stress forces in the tendons. Savelberg, Herzog [54] designed a multilayer network, fed by EMG signals from the *gastrocnemius* muscle, which generated force values measured by a gauge fixed to the tendon. The study, conducted on three cats, included three experiments:

- Simultaneous recording of force and EMG at constant gait velocity on a mechanical treadmill,
- EMG was recorded, force was measured and compared with that predicted by ANN simulation (the treadmill ran at three different velocities),
- Forces in one animal were predicted from EMG values recorded in the other two cats running at various velocities.

This is, so far, the only report found in the literature in which muscle forces predicted from EMG signals during gait by ANN simulation were verified experimentally. The results may be regarded as reliable as the simple and multiple correlations between the predicted and observed values were high in all versions and ranged from $R^2 = 0.71$ to $R^2 = 0.98$.

Liu and Lockhart [13] attempted at creating a network capable of reproducing muscle forces during gait from EMG signals recorded in working muscles. The bioelectric activity and force of the *soleus* muscle were recorded, the experimental protocol from the previous experiment being exactly reproduced. The objective of the study was to make use of the experience in the construction of ANN and to apply advanced mathematical procedures to identical experimental conditions. The authors emphasized their achievement consisting in constructing a network with three latent layers with a single input containing multiple EMG(t) signal cells and a single F(t) output, capable of reproducing muscle forces with an accuracy equal to $R^2 = 0.9$ and $RSE < 15\%$ by processing data from various animals.

Conclusions

Summing up, the following issues remain to be solved:

- a. Models of distributions of muscle forces in diverse muscular and neural pathologies;
- b. The SIMM software and the available model of lower extremity movements in gait are not suited for reproducing pathological gait resulting from a deficient muscle strength or neuromuscular co-ordination, as the software was designed for normal gait;
- c. It is not possible to design a reverse simulation, i.e. predicting muscle activity from the mechanics of pathological gait.

The available literature offers several mathematical procedures, including ANN, for modelling muscle work in specific movements of the whole body or of its segments, the ANN being particularly useful in studying biological objects for the following reasons:

- a. It enables analysis of non-linear relationships between parameters and between subjects;
- b. ANN procedures are distribution-free;
- c. Both continuous and categorised variables can be easily processed;
- d. Outliers and missing data are easily managed;
- e. ANN procedures are noise- and interference-resistant.

The principal advantage of ANN is the capacity to conduct simulations and designing models having a limited number of observations and a large number of variables at the disposal. In contrast to deterministic methods, ANN techniques do not require complicated procedures of establishing physical modelling followed

by mathematical description, which makes ANN a handy analytical tool in practically any experimental area. Thus, ANN gains increasing application in biomechanics and shall be employed in future research.

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Paper received by the Editors: October 20, 2008.

Paper accepted for publication: October 27, 2008.

Address for coresspondence

Andrzej Wit
Akademia Wychowania Fizycznego Józefa Piłsudskiego
ul. Marymoncka 34
00-968 Warszawa, Poland
e-mail: andrzej.wit@awf.edu.pl



A STUDY OF ELECTROMYOGRAPHY OF LOWER EXTREMITIES AND COMPARISON OF EFFECTS OF PLYOMETRIC AND ISOTONIC WEIGHT TRAINING

DOI: 10.2478/v10038-008-0011-x

Abdol Rahman Mehdipour¹, Mohamad Hasan Ferdowsi^{2*}, Aydi Alijani¹, Shahin Goharpey³

¹ Shahid Chamran University, Ahwaz, Iran

² Payame Noor University, PNU, Iran

³ Jondi Shapour Medical Sciences University, Ahwaz, Iran

ABSTRACT

Purpose. The purpose of this study was to investigate and compare the effects of plyometric and weight (isotonic) training on lower extremity electromyography in physical education students. **Basic procedures.** In this study, 45 students from the physical education and sport sciences faculty of Shahid Chamran University were selected and divided in 3 groups (plyometric – 15, weight – 15, control – 15). Two experimental groups participated in a 6 week and a 3 week period sessions. The electrical changes of muscles were measured using sergeant test for explosive power and squat test for absolute power. **Main findings.** The data was collected via MT8 and analyzed using MBM. The results of the variance analysis test (ANOVA) were compared with the average values of electromyography changes (explosive and absolute power) and it was shown that electrical changes (explosive and absolute power) of biceps femoris muscle in all groups were non-significant whereas electrical changes (explosive and absolute power) of rectus femoris and gastrocnemius muscles were significant.

Key words: explosive power, absolute power, electromyography, biceps, rectus femoris, gastrocnemius

Introduction

Physical fitness has always been considered as a key factor in the success of any athletic endeavour and in the improvement of sports records. Attaining physical fitness along with acquiring effective techniques and skills in any sports can lead professional athletes to the highest levels of professional championship and the setting of impressive records. Among the crucial factors in the realization of physical fitness is the physical strength of the athletes which is the cornerstone of any sports achievements. Efficient application of other physical abilities such as speed, power agility and endurance mainly depends upon adequate physical strength of the individual. Thus, strength should be seen as the most important physical ability of the professional athletes that plays a leading role in all of the champion sports [1]. Selection of a suitable training schedule to enhance physical stamina (explosive power, absolute power) can become a solid foundation for athletes and trainers to

attain success. Such a selection is essentially based upon the available sports facilities, varying environmental conditions and the approach adopted by the athletes and trainers and their knowledge of various training techniques. According to the results of related studies presented in the literature, weightlifting and plyometric trainings are important activities in strength-developing programs. Weightlifting increases the physical strength and a progress of 25 to 100% can be observed in the muscles after performing a weightlifting training schedule of 3 to 6 months [2]. Plyometric or *drop-jump* exercises are amongst the newly-developed endurance training techniques that were introduced in the late 1980s to improve the athlete's jumping skills used chiefly to fill the gap between speed and strength exercises to activate more kinetic elements. Numerous studies confirm that plyometric exercises are an effective tool in the empowerment of the athletes. Such training schedules have also been brought into focus because of the constructive effects they have upon the speed, agility and even flexibility of professional athletes [3]. Yet, the question is whether plyometric exercises are effective in the development of ultimate power of the ath-

*Corresponding author.

lete and whether such training is as effective in the strengthening of athlete's legs as training using weights? Is the EMG of the muscles of the lower torso similar in training via weights (isotonic training) and plyometric training? There is a vast literature in which the effectiveness of plyometric training and training via weights is shown and verified, yet in the current research the aim is to determine the effect of both types of training by comparing the electromyography of each method upon the behaviour of the lower torso muscles.

Material and methods

The type of research carried out is applicable in nature and semi-empirical. The sample population was composed of forty-five male college students majoring in Physical Education at the University of Shahid Chamran in Ahwaz City. The type of sampling was random in nature; 60 students were selected from among the students at the faculty of Physical Education and the Wingate Test was applied to the said population using an 894E Anaerobic Test Ergometer Cycle/Bike (Monark, Sweden) in order to determine the extent of the non-aerobic preparation of the participants. From among the said group 45 participants had sufficient non-aerobic preparation in order to participate in the study. The study group was then divided into three empirical and control groups of 15 students each.

Statistical Methods Applied in the Analysis of the Data: In order to determine the mean and standard deviation of the results obtained in the research carried out and to present the said data in tabular form descriptive statistics were used. In order to study the significance of the results obtained a correlated T-test was applied, then a comparison between the groups was carried out using an ANOVA variance and in order to determine the differences between the trained groups the Tokey follow-up test was applied. The results obtained were all within the range $\alpha = 5\%$.

Results

Stamina is one of the most important elements in developing physical fitness and is applicable in almost all sport activities. In order to succeed in any individual or team sport activity it is necessary to have the required physical fitness and even though an outstanding athlete requires to be physically fit in every muscle, with the muscles of the lower torso having the highest priority. As seen in Tab. 1, the following conclusions can be inferred: the six week training with weights (isotonic training) had no effect on the Emg (total power and explosive power) of the leg rectus femoris whereas the six week training program using weights (isotonic training) had an effect on the Emg (total power and explosive power) of the leg gastrocnemius. Besides the six week training

Table 1. The descriptive variables for the squat pre-test and post-test in the isotonic training group

Variables/ Statistical Variables		Number of candidates	Average of Emg variations	Minimum Emg	Maximum Emg	Difference on average
Leg rectus	Pre-test	15	1/708	0/84	2/60	0/094
femoris	Pre-test	15	1/802	0/90	2/90	
Right thigh	Pre-test	15	2/484	1/20	4/20	1/528
muscle	Pre-test	15	4/012	2/44	5/60	
Double inner	Pre-test	15	0/884	0/20	2/10	0/283
muscle	Pre-test	15	1/366	0/50	3/10	

Table 2. The descriptive variables for the squat pre-test and post-test in the plyometric training group

Variables/ statistical variables		Number of candidates	Average of Emg variations	Minimum Emg	Maximum Emg	Difference on average
Leg rectus	Pre-test	15	1/681	0/42	2/61	0/209
femoris	Pre-test	15	1/890	0/44	2/90	
Right thigh	Pre-test	15	1/215	0/53	4/20	0/675
muscle	Pre-test	15	1/332	0/51	5/60	
Double inner	Pre-test	15	1/535	0/20	2/65	0/371
muscle	Pre-test	15	1/906	0/46	3/25	

program using weights (isotonic training) had an effect on the Emg (total power) of the right thigh muscles but not on the Emg (explosive power) of the said muscle.

It is noteworthy that from the results obtained in Tab. 2 one can see that six weeks of plyometric training had no effect on the Emg (total power and explosive power) of the leg rectus femoris and the six week of plyometric training program had no effect on the Emg (total power) of the right thigh muscles but had an effect on the Emg (explosive power) of the leg gastrocnemius muscle. The results show that there was no significant change in the Emg of the rectus femoris muscles of the leg (total power and explosive power) in all groups but there was a significant difference in the Emg of the leg gastrocnemius in all groups.

Discussion and Conclusions

The results obtained in general show that plyometric training will have the same effect as using weights to increase the total stamina and the explosive power of the muscles of the lower torso in college students. The comparison of both methods showed a significant difference and also a lack of difference between the effects of plyometric and isotonic training on the total stamina and the explosive power of leg rectus femoris, gastrocnemius and right thigh muscles. It is worth noting that the increase in the total stamina of the isotonic and plyometric training group was slightly higher than that of the other empirical group. The results obtained show that the Emg (total stamina) variations for the gastrocnemius muscle with an estimation of $p = 0/009$ and on a level of $\alpha = 5\%$ are significant.

Therefore, it can be inferred that a six week plyometric training program with a three day a week schedule will have a significant effect on the increase in the variations of Emg (total stamina) of the twin muscle. This is also verified by the studies carried out by Myer et al. [4], Chimera et al. [5], Lephart et al. [6] and Toumi et al. [7], yet the findings of Doyle and Reilly [8] reject such results. One of the reasons could be the lack or correlation between the Reilly and Dual's research and the other research conditions, the fact that the training sessions took place during the peak sport season. It is worthwhile to note that the results obtained show that the variations in the Emg (total stamina) for the gastrocnemius muscle with an estimation of $p = 0/584$ and for the right thigh muscle with an estimation of $p = 0/249$ and on a level of $\alpha = 5\%$ lack any significance.

It can thus be stated that a six week plyometric training period with a spacing of three sessions a week does not have a significant effect on the Emg variations in the right thigh muscles and the gastrocnemius muscle, see the findings of Myer et al. [4], Chimera et al. [5], Toumi et al. [7], Swanik et al. [9], as well as those of Doyle and Reilly [8] show opposing results. This may be due to the fact that in the studies performed by Doyle and Reilly the level of exercises carried out and amount of plyometric training were less than those specified in other researches, albeit in Dual and Reilly's research the training was carried out at the end of the exercise period and biking exercises which might also contribute to the variation in results. From the comparison of the statistical elements one can see that variations in Emg (total stamina) of the gastrocnemius muscle in particular groups show a significant difference ($p = 000$), i.e. after the post-test the difference between the isotonic and plyometric training groups ($p = 000$) and also the plyometric and control groups ($p = 000$) had a meaningful significance; however, as regards the difference between the isotonic training group and the control group there was no meaningful significance ($p = 0/494$). The results of the study show that plyometric training has a greater effect on the development and increase of explosive power in the gastrocnemius muscle, yet if applied correctly isotonic training is also effective in the development of the said muscles within the specified period, thus verifying the results obtained by Blattner et al. [10], Yang, et al. [11], Robinson et al. [12] and Valkeinen et al. [13].

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Paper received by the Editors: June 3, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence
Mohamad H. Ferdowsi
Payam Noor University of Ahwaz
Pardis Boulevard
Ahwaz City, Iran
e-mail: mferdowsi1359@gmail.com



EFFECTS OF ACCELERATED BREATHING ON POSTURAL STABILITY

DOI: 10.2478/v10038-008-0012-9

Michał Kuczyński^{1, 2*}, Marcin Wieloch¹

¹ Opole University of Technology, Opole, Poland

² University School of Physical Education, Wrocław, Poland

ABSTRACT

Purpose. The aim of the paper was to determine the effect of respiration on body balance in quiet standing. **Basic procedures.** Postural performance during quiet standing was compared in 37 young healthy subjects in two trials on a force plate: first with natural breathing, and then with accelerated high-volume breathing at the rate of 1 Hz. Each trial included 20 s quiet standing with eyes open, and the center of pressure (COP) was recorded with the sampling rate of 20 Hz in both anterior-posterior (AP) and medial-lateral (ML) planes. Based on the recorded signals the COP dispersion measures and postural frequency were calculated. **Main findings.** The forced respiration contributed significantly to the increase in all COP stability measures in the AP plane: dispersion ($p < 0.01$), range ($p < 0.001$) and mean velocity and frequency ($p < 0.00001$). In the ML plane only mean velocity ($p < 0.001$) and frequency ($p < 0.01$) were affected. **Conclusions.** In view of the evidence provided by other authors that stress tests increase the amplitude- and frequency-based stability measures, our results indicate that the contribution of natural accelerated breathing after strenuous physical exercise will bias the results of stabilographic studies, rendering them worthless in understanding the role of neuromuscular fatigue in stability deterioration. Such studies must use data collected after the respiration returns to normal rate. However, if the study aims at overall assessment of postural stability post-fatigue, the postural testing may be performed immediately after the stress test.

Key words: postural sway, body balance, respiration, fatigue

Introduction

One of the most common experimental paradigms used in body balance studies is assessment of the effects of physical exercise on selected parameters of postural stability [1, 2]. For individuals, especially elderly people, who are characterized by deficits of postural control, the insufficient resistance to fatigue of their system of equilibrium can be the cause of falls [3]. In the case of athletes resistance to fatigue can be decisive for their final training results [4]. The most common method of evaluation of postural stability is stabilography, which permits the recording of oscillations of the center of pressure (COP) on two planes [5].

In order to assess correctly changes of body balance due to physical fatigue it is necessary to know the effects of natural mechanical processes accompanying the impact of physical exercise on the stabilographic parameters. This concerns in particular the impact of

accelerated breathing on the positioning of the center of mass (COM) of the whole body, causing rhythmic changes of the chest volume and generating extra force [6]. Apart from the studies by Hunter and Kearney [7] and Jeong [6], who showed an increase of the COP mean velocity with breathing frequency, the correlation between increased pulmonary ventilation and postural stability has been largely neglected. Only Hodges et al. [8] and Hamaoui et al. [9] studied these relationships in the context of postural compensation for respiration with simultaneous anticipatory movements of hip and knee joints. On the other hand, Caron et al. [10] compared COP measures in trials during natural breathing and apnoea.

The lack of professional literature on the effects of breathing rate, inconsistencies in reports on the impact of fatigue on postural stability [1, 2] and development of methodology of measurement of postural control in the last decade [5, 11, 12] point to the need of further research on the effects of accelerated high-volume breathing on the parameters of postural stability in subjects at rest. Considering different anatomical and physiological

*Corresponding author.

factors, it can be assumed that the measures of COP dispersion and frequency should increase in the anterior-posterior plane (AP) and remain unchanged in the medial-lateral plane (ML).

Material and methods

The study sample included 18 male students and 19 female students ($n = 37$) of the Technical University of Opole, aged 22–23 years, with no health conditions affecting their body balance. The subjects' mean body weight was 66.4 ± 14.0 kg, and their mean body height 173.3 ± 7.7 cm. The subjects were to perform two trials during quiet standing on a force plate with their eyes open: first with natural breathing, second with accelerated high-volume breathing. The respiration in the second trial was forced with the use of a metronome. The entire breathing cycle (inhaling followed by immediate exhaling) was performed at the rate of 1 Hz. Both trials lasted 20 s each, with a 30 s break in between, without stepping off the plate. During the trials COP signals were recorded in the medial-lateral plane (ML) and the anterior-posterior plane (AP) with the sampling rate of 20 Hz.

On the basis of the recorded signals the traditional COP stability measures were calculated: dispersion, range, mean velocity and frequency of the corrected signal [13]. The corrected signal was calculated by subtracting an approximate COM signal from the COP signal using exponential smoothing [13]. To analyse the differences between the calculated measures in both trials a t-test for repeated measures was used (Statistica 7.0) at $p < 0.05$.

Results

The results of both trials are presented in Table 1. The metronome-forced respiration contributed to a 23%

increase of COP dispersion and range and 141% increase of mean velocity in the AP plane. Also a 39% increase in the frequency of the corrected signal was recorded. The respective changes in the ML plane were observed in the mean velocity (31% increase), due to forced respiration, and frequency (12% increase).

Discussion

The aim of the study was to evaluate the effects of mechanics of chest movements of healthy rested subjects, force-breathing at the rate of 1 Hz, on selected measures of postural stability during quiet standing. As previously assumed forced respiration caused a significant increase of the COP dispersion, and increase of the frequency of the COP-COM signal in anterior-posterior plane (AP). The COP mean velocity in the AP plane was two times higher. In the ML plane the only significant difference between the trials was observed in the increase of mean velocity. The results obtained confirm the hypothesis assumed and correspond to the results of other authors. However, a more detailed analysis reveals that Jeong [6] noted a mere 23% increase of mean velocity in subjects breathing at an accelerated rate of 0.4 Hz as opposed to subjects breathing naturally. Whereas data obtained by Hodges et al. [8] point to a three-times increase of COP amplitude due to the high-volume respiration at the natural rate in comparison with natural breathing. This unusually great increase of dispersion of COP data in Hodges et al. [8] might be partially explained by the longer stress test duration (2 min) in their study. Another reason for the observed discrepancy between our results and those of Hodges et al. [8] could be possible hyperventilation effects on postural sway mechanisms due to reduction of the CO_2 blood level [14]. Taking into account the above observations and differences between individual tests it can be postulated that in the most common case, short (20–30 s) post-ex-

Table 1. Comparison of the mean values (\pm SD) of COP parameters examined during quiet standing tests with natural breathing (Nat) and accelerated high-volume breathing at the rate of 1 Hz

	Medial-lateral plane		Anterior-posterior plane	
	Nat	1 Hz	Nat	1 Hz
D (mm)	3.9 ± 1.5	$4.8 \pm 2.5^*$	2.8 ± 1.0	2.9 ± 1.0
R (mm)	19.3 ± 8.5	$23.7 \pm 11.0^{**}$	14.3 ± 5.1	14.6 ± 2.9
MV (mm/s)	8.2 ± 2.5	$19.8 \pm 11.3^{***}$	7.1 ± 2.4	$9.3 \pm 3.8^{**}$
F (Hz)	0.54 ± 0.14	$0.75 \pm 0.19^{***}$	0.69 ± 0.15	$0.77 \pm 0.15^*$

D – dispersion, R – range, MV – mean velocity, F – frequency of the corrected signal, $^*p < 0.01$, $^{**}p < 0.001$, $^{***}p < 0.00001$

ercise tests of postural stability, COM oscillations induced by more intensive breathing should significantly increase the mean velocity of the COP and moderately increase the parameters of variability of this signal. However, the distinction between the mechanical and physiological effects on the changes observed seems highly unlikely, or not possible at all. The observed disproportionately high increase of COP mean velocity in comparison with the COP dispersion can be explained by the periodical component value in the signal induced by forced respiration at a high rate.

Another problem is the influence of fatigue on the frequency of the corrected signal. The results of this study point to an increase in the frequency; however, the question of the precise cause of it arises. It remains an open question whether the noted increase in the frequency was caused by fatigue itself, or by mechanical results of fatigue due to cyclic changes generated by the respiratory system. Hodges et al. [8] carried out a spectroanalysis of the COP and noted distinct peaks in the power spectrum of the signal consistent with peaks of chest movements. The amplitude of these peaks was slightly lower than the mean power of the COP signal for natural breathing, and dominant for high-volume breathing at the natural rate. Considering these observations and results of our study it seems plausible that the noted increase of the corrected signal could have largely resulted from dynamic breathing rather than from fatigue itself.

Conclusions

The obtained results can be applied in research practice. An important question arises whether postural stability should be evaluated immediately after exercise without waiting for return to the normal breathing rate, or should all the factors be treated together as a collective disturbance of the body balance immediately after exercise. It seems that the latter is the only justified approach facing the need of total, functional evaluation of postural stability after exercise, which is the case in sport. On the other hand, if we want to understand the processes of muscle fatigue and their effects on the system of equilibrium, the former approach is proper as it eliminates a few interfering variables and makes the interpretation of results easier.

It should be noted, however, that the above problems refer to the traditional measures of postural stability, which depend on chest movements and com-

pensatory body movements. The results should be interpreted with utmost caution. A good methodological indication is application of new measures of postural stability, which, at least in theory, should be highly resistant to the COP-related interference. They include chaotic measures [11, 15] and time-to-boundary measures [12]. The experimental verification of these suggestions will constitute an enormous development in research on postural stability during quiet standing.

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Paper received by the Editors: June 3, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence

Michał Kuczyński
Katedra Fizjoterapii
Akademia Wychowania Fizycznego
al. I.J. Paderewskiego 35
51-612 Wrocław, Poland
e-mail: michkucz@awf.wroc.pl



CHANGES OF MAXIMAL MUSCLE TORQUE AND MAXIMAL POWER OUTPUT OF LOWER EXTREMITIES IN MALE JUDOISTS DURING TRAINING

DOI: 10.2478/v10038-008-0013-8

Krzysztof Buśko^{1, 2*}, Anna Nowak²

¹ Department of Biomechanics, Institute of Sport, Warsaw, Poland

² Department of Combat Sport and Weightlifting, Józef Piłsudski University of Physical Education, Warsaw, Poland

ABSTRACT

Purpose. The aim of the study was to follow changes of the maximal muscle torque and maximal power output of lower extremities in male judoists during pre-competition training (PCT). The original hypothesis assumed that different training loads would cause changes of the maximal muscle torque and maximal power output of legs in male judoists during pre-competition training, but not changes of the topography of the maximal muscle torque in all muscle groups. **Basic procedures.** The study sample consisted of five male judoists from the Polish National Team. Muscle torque measurements in static conditions were performed shortly before PCT (I), after the strength training mesocycle (II) and immediately after PCT (III). Ten muscle groups were examined: flexors and extensors of the trunk, shoulder, elbow, hip and knee. The maximal power output of legs was measured on a dynamometric platform during counter-movement jumps (CMJ) and bounce counter-movement jumps (BCMJ). **Main findings.** The sums of the muscle torque of both arms and the trunk were changed insignificantly during pre-competition training (PCT). The sum of muscle torque of the right and left lower extremities increased significantly between the measurements I and III. The muscle percent topography of muscle groups also showed significant changes. Maximal power output of lower extremities measured during CMJ decreased significantly, but increased during BCMJ. **Conclusion.** PCT caused changes of the maximal muscle torque of lower extremities, but the muscle topography of the muscle groups revealed significant changes, too. The maximal power output of lower extremities measured during CMJ decreased.

Key words: bounce counter-movement jump (BCMJ), counter-movement jump (CMJ), judo, muscle percent topography, muscle torque, power output

Introduction

Changes of the maximal muscle torque and power output of legs are indicative of the athlete's training level and effects of applied training loads. Most often, the maximal muscle torques of flexors and extensors of the arms, legs and trunk in static and dynamic conditions are used for the testing purposes [1, 2]. The muscle torque can also be represented as the percent contribution of particular muscle groups [2–4]. Maximal power output of legs is measured during jumps on a dynamometric platform [5, 6] and/or with cycle ergometer tests [7–9].

Success in judo requires perfect physical and tactical preparation [10, 11]. The planning of judo training should not only concern the applied training loads, but

it should also focus on the practitioners' physical abilities. The measurement of the maximal static muscle torque and maximal power output of legs yields valuable information that can be extremely useful in judo training planning [12].

The aim of the study was to examine changes of the maximal muscle torque and maximal power output of judoists' legs during pre-competition training (PCT). The original hypothesis was that the different training loads would cause changes of the maximal muscle torque and maximal power output of legs in male judoists during pre-competition training, but not changes of the topography of the maximal muscle torque of all muscle groups.

Material and methods

The study was approved by the Research Ethics Committee. The study sample consisted of five judoists

*Corresponding author.

of the Polish National Team, aged 24.7 ± 2.1 years. The subjects' mean body height was 174.8 ± 5.9 cm, and body weight 76.0 ± 6.0 kg (I), 76.8 ± 6.2 kg (II) and 76.3 ± 7.3 kg (III). The subjects' body weight did not change significantly. Three measurements were carried out: before the PCT (I), immediately after the strength training mesocycle (II), immediately after PCT (III).

Measurement of the maximal muscle torque in static conditions. The maximal muscle torque of ten groups of muscles: flexors and extensors of the elbow, shoulder, hip, knee and trunk was measured in static conditions [3]. During the measurement of the muscle torque of elbow flexors and extensors the subject was sitting, with his arm bent at a right angle and placed on the armrest, and with the trunk stabilized. The muscle torque of shoulder flexors and extensors was measured in a sitting position. The flexion angle was 70° and the extension angle 50° . The trunk was stabilized and the chest pressed against the testing station. The measurements of muscle torque of knee flexors and extensors were carried out on subjects in a sitting position. The hip and knee joints were bent at 90° . The subjects were stabilized at the level of anterior iliac spines and thighs, with the legs resting on the chest. The subjects were lying face down during the measurement of the muscle torque of hip extensors, and face up during the measurement of the muscle torque of hip flexors. The hip joint angle remained at 90° during measurement. The maximal extension of the elbow, knee and hip joints was accepted as 0° . For the shoulder joint, the positioning of the arm along the side was taken as 0° . The axis of rotation during the muscle torque measurement corresponded to the axis of rotation of the torque meter. The right arm and left arm muscles were measured separately, always in the flexion–extension sequence. Each subject was supposed to achieve the maximal power output during measurement.

The power output of lower extremities and the height of elevation of the center of mass during vertical jumps were measured on a dynamometric platform with a Kistler amplifier for counter-movement jumps (CMJ) and bounce counter-movement jumps (BCMJ). The amplifier was connected to a PC via an a/d converter. The MVJ v. 3.4. software package was used for measurement. In the physical model applied the subject's body mass bouncing on the platform was reduced to a particle affected by the vertical components of external forces: the body's gravity force and the vertical component of the platform's reactive force. The maxi-

mal power and maximal height of the center of mass elevation (h) were calculated from the registered reactive force of the platform [5]. Each subject performed six vertical jumps with maximal force on the dynamometric platform: three counter-movement jumps (CMJ) and three bounce counter-movement jumps (BCMJ). There were 5 s breaks between the CMJs, and 1 min breaks between the BCMJ. The jump with the highest elevation of the body's center of mass was chosen for statistical analysis.

All measurements were performed in the morning; the subjects were informed about the aims and methodology of the tests prior to the measurements.

The results were statistically processed with the use of analysis of variance (ANOVA) for repeated measures. The statistical significance of the differences between the mean values was assessed with the post hoc least significant difference test (LSD test). The level of statistical significance was set at $p < 0.05$. All calculations were made with the aid of Statistica (v. 5.5, StatSoft) software package.

Results

Tab. 1 presents the maximal muscle torque values (M_m) achieved by the judoists under study. No significant changes were observed in the sum of the maximal torque of both arms, sum of the maximal muscle torque of the right arm and sum of the maximal muscle torque of the left arm. The sums of the maximal muscle torque of the right leg and the left leg increased between the measurements I and II by 5.8% and 2.3%, respectively; and increased significantly between the measurements I and III by 20.5% and 20.7%, respectively. The sum of the maximal muscle torque of the trunk remained unchanged between the measurements I and II (0.4%), and then decreased by 7.7%. Tab. 2 presents the maximal muscle torque values as the mean percent contributions of particular muscle groups. A significant difference of the percent topography of the sum of the maximal muscle torque of the left arm, right leg, left leg and trunk between the measurements I and III was noted. The CMJ and BCMJ results are presented in Tab. 3. The maximal power output of the legs during counter-movement jumps decreased significantly between the measurements I and II by 9.7%, but the difference was non-significant between the measurements I and III (decrease by 6.8%). The changes in the maximal power output during bounce counter-movement jumps and

jump height measured during CMJ and BCMJ were statistically non-significant.

Discussion

Professional literature includes a number of works on exercise physiology of male and female judoists [13–

15], but there are very few studies concerned with judoists' biomechanics [1, 16].

The aim of pre-competition training (PCT) is to make athletes achieve the highest level of physical characteristics and prepare them for the main competition of the season. Therefore at different PCT stages changes of physical characteristics of athletes should be noted. The present study revealed a non-significant increase of the sum of the maximal muscle torque (M_m) of the upper and lower extremities; a decrease in the sum of the maximal muscle torque of the trunk between the measurement before PCT (I) and after the strength training mesocycle (II); a significant increase in the sum of the maximal muscle torque of the right leg and left leg; and a decrease in the sum of the maximal muscle torque of the trunk and the left arm immediately after PCT (III). Trzaskoma [2] showed that after three years of training, the percent contribution of the maximal torque of arms in the sum of the muscle torque of all muscle groups increased by 1.7%, whereas the relative value of the sum of the maximal muscle torque of the arm, trunk and the sum of the muscle torque of ten muscle groups decreased significantly by 5.9%, 7.5% and 4.6%, respectively. In a two-year training cycle the muscle torque value increased by about 3%.

Literature lacks explicit and unambiguous conclusions about changes of power output during different types of jumps performed after different kinds of training [17–19]. Kubo et al. [18] noted no changes in the height of the body's center of mass during a CMJ (0.3%) after a 12-week isometric strength training. In Harris et al. [17] strength training did not increase jump height measured during CMJ, whereas high “force” training (strength training with 30% of maximal isometric force) increased jump height during a CMJ and a standing long jump. Prouteau et al. [19] noted a significant decrease in jump height measured with the Sargent test,

Table 1. Changes of mean values (\pm SD) of the sums of the maximal muscle torque ($N \cdot m \cdot kg^{-1}$) of the right (R) and left (L) upper extremity (SUE), lower extremity (SLE), trunk (ST), both upper extremities (SUEE), both lower extremities (SLEE) and all ten muscle groups (TOTAL) during PCT

Variables	measurement I	measurement II	measurement III
SRUE	4.91 ± 0.82	5.06 ± 0.68	5.26 ± 0.35
SLUE	4.87 ± 0.49	5.06 ± 0.48	4.62 ± 0.17
SRLE	14.84 ± 0.20	15.71 ± 1.34	$17.87 \pm 1.15^{a,b}$
SLLE	14.74 ± 1.70	15.95 ± 1.22	17.64 ± 1.41^a
SUEE	9.78 ± 1.26	10.12 ± 1.06	9.88 ± 0.48
SLEE	29.58 ± 1.58	31.66 ± 1.64	35.52 ± 2.35^a
ST	12.02 ± 0.56	11.97 ± 1.15	11.09 ± 1.18
TOTAL	51.38 ± 1.83	53.75 ± 3.41	56.49 ± 2.68^a

^a significantly different from the measurement I,

^b significantly different from the measurement II

Table 2. Changes of mean values (\pm SD) of topography of the maximal muscle torque (%) of the right (R) and the left (L) upper extremity (SUE), lower extremity (SLE) and trunk (ST) during the PCT

Variables	measurement I	measurement II	measurement III
SRUE	9.55 ± 1.52	9.41 ± 1.05	9.32 ± 0.76
SLUE	9.49 ± 0.96	9.41 ± 0.60	8.20 ± 0.58^{ab}
SRLE	28.91 ± 1.14	29.21 ± 1.48	31.64 ± 1.17^{ab}
SLLE	28.66 ± 2.72	29.73 ± 2.26	31.20 ± 1.34^a
ST	23.40 ± 0.85	22.24 ± 0.89	19.64 ± 1.97^{ab}

^a significantly different from the measurement I,

^b significantly different from the measurement II

Table 3. Changes of mean values (\pm SD) of the height of elevation of the body's center of mass (h), maximal power output (P_{max}) during counter-movement jumps and bounce counter-movement jumps on a dynamometric platform during PCT

Variables	measurement I	measurement II	measurement III
P_{maxCMJ} (W)	3122.300 ± 753.200	2819.300 ± 768.000^a	2911.300 ± 798.100
$P_{maxCMJ}/mass$ (W/kg)	40.340 ± 6.460	35.850 ± 6.790^a	37.520 ± 7.350
h_{CMJ} (m)	0.502 ± 0.048	0.494 ± 0.052	0.507 ± 0.055
$P_{maxBCMj}$ (W)	4113.000 ± 1214.20	4313.800 ± 832.500	4011.500 ± 812.200
$P_{maxBCMj}/mass$ (W/kg)	52.990 ± 11.710	55.400 ± 9.300	52.140 ± 9.200
h_{BCMj} (m)	0.605 ± 0.079	0.599 ± 0.056	0.599 ± 0.053

^a significantly different from the measurement I

from 44 to 40 cm, after a six-month training, and to 36 cm after further 3-week training during the season. The present study did not reveal any significant changes in the height of the body's center of mass during CMJ and BCMJ. However, the power output during BCMJ saw a non-significant increase between the measurements I and II, and then it decreased. In the case of power output during CMJ a significant decrease of power between the measurements I and II, and a non-significant decrease of power between the measurements I and III were noted. We are not able to provide any sufficient explanation of these results. CMJ and BCMJ are performed differently. During CMJ the jump height and power output are assessed with the body's center of mass lowered before the jump and the leg muscles working in the extension-flexion sequence. During BCMJ also the lowered body's center of mass is used as well as the horizontal velocity of the body's center of mass during a run-up. A comparison of the body height during CMJ and BCMJ also allows assessment of coordination of the run-up and bounce stages of the jump. In volleyball players the difference in the height of the body's center of mass between CMJ and BCMJ was about 0.13 m, and in power output 18.99 W/kg. In the judoists the difference between the jumps was 0.10 m during the measurement I, 0.11 m during the measurement II and 0.09 m during the measurement III. According to Häkkinen [12] long-lasting, intensive training should mainly affect the maximal power output, whereas the increase in the explosive force should be relatively lower. This might serve as an explanation for the increase in the maximal muscle torque of the legs, a non-significant decrease in power output during the vertical jumps, and lack of changes in jump height observed in the present study.

Conclusions

The obtained results confirm the research hypothesis only partially:

1 The following changes were observed in the judoists under study during the pre-competition training:

- Decreases in the sums of the maximal muscle torque of the trunk and of the left leg between the measurements at the beginning (I) and immediately after (III) PCT.
- Increases in the sums of the maximal muscle torque of the right leg and the left leg (significant) and of the right arm (non-significant).

2. The topography of the muscle torque was significantly changed, with the exception of the percentage contribution of the sum of the maximal muscle torque of the right arm.

3. The jump height, measured with the height of the body's center of mass as well as power output during BCMJ remained unchanged during pre-competition training. During CMJ no changes in the jump height were observed as well as a decrease in the maximal power output.

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Paper received by the Editors: June 3, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence

Krzysztof Buśko
Zakład Biomechaniki
Instytut Sportu
ul. Trylogii 2/16,
01-982 Warszawa
e-mail: krzysztof.busko@insp.waw.pl



THE DYNAMICAL ASYMMETRY OF THE UPPER EXTREMITIES DURING SYMMETRICAL EXERCISES

DOI: 10.2478/v10038-008-0014-7

Marcin Jaszczak

University School of Physical Education, Wrocław, Poland

ABSTRACT

Purpose. The purpose of the study was to estimate the influence of the symmetrical movements, mirror (breaststroke) and translational (front crawl) ones, on the dynamical asymmetry of upper limbs. **Basic procedures.** Thirty six students (15 males and 21 females) took part in the study. The forces produced by the subjects' upper limbs during breaststroke and front crawl simulation on the swimming ergometer (Weba, Germany) were recorded. Then the coefficient of dynamical asymmetry was computed. **Main findings.** Breaststroke movements revealed lower dynamical asymmetry of upper limbs than front crawl ones for men as well as for women. Greater differences between the types of movement under study were observed in women. **Conclusions.** It might appear that males can use interchangeably both techniques during symmetrization. However, for women, first of all the mirror symmetry movements should be used. So, selection of exercises for symmetrization of movements of upper limbs should be based on the gender factor, too.

Key words: postural defects, swimming, dynamical asymmetry

Introduction

Optimal posture is the state of muscular and skeletal balance. Looking at the mirror you can see the symmetry between the right and left sides of the body (even organs). But careful observation will let you find differences even between the two sides of the face [1]. There are different types of asymmetry known [2]:

- morphological (expressed as the differences in: circumference, length, width, shape or proportions between even organs),
- functional (variance in frequency of use, accuracy of movement),
- dynamical (differences in the muscle strength between the body sides).

Their accumulation is one of the reasons of postural defects [3]. Faulty posture can induce a malfunction of any system of the human body. Children suffering from the minor postural defects are usually first treated by the physical exercises [4]. The symmetrical drills are most often used [5]. Water environment, because of its physical properties, creates good conditions for treating locomotor apparatus diseases. It is swimming that is most often recommended [6]. It involves the whole human movement system providing minimum stress on the body and reducing muscular imbalance in musculo-

skeletal system. During water locomotion movements of the upper limbs play the main role [7, 8]. It is currently held that propulsion in swimming is achieved by forces predominantly generated by the hands [8]. Therefore, the influence of movements of the upper extremities on the swimming efficiency is often studied [7].

Breaststroke and butterfly are the mirror symmetry techniques and could play the main role during kinesiotherapy in water. However, the butterfly is coordination and strength demanding. So, it is seldom used. Breaststroke is contraindicated in knee joint defects. On the other hand, front crawl and backstroke are the translational symmetry techniques; the same configuration of extremities is cyclicly repeated in the same direction. These techniques seem to be the more natural form of locomotion because of alternating limb movements, like in walking. Moreover, during translational swimming the spine is located all the time at horizontal, gravity relieved, position. Some studies indicated small deficiency of symmetry of the upper limbs during front crawl swimming [9, 10]. For the lower limbs asymmetry was evident during breaststroke, higher for men, and its magnitude increased together with the swimming velocity [11, 12]. It seems that the upper extremity symmetry during breaststroke was assumed. Therefore, a total lack of studies comparing their symmetry in

breaststroke during swimming is observed. However, some studies performed on the land revealed asymmetry of the upper limbs during breaststroke simulation [13, 14]. There are results of studies of the four swimming techniques and their effects on the spine in the sagittal plane [15], but no information has been found about their influence on the body in the frontal plane. Probably it was assumed that symmetrical exercises in water equally increase balance of the body. However, it might appear that mirror symmetry exercises are more efficient in the pursuit of muscular symmetry than translational ones [16]. But is this difference so significant as to recommend mirror swimming techniques without regard of possible danger of knee injury. Moreover, the horizontal body position during the front crawl and backstroke is highly beneficial.

So, the purpose of the study was to estimate the influence of the forms of symmetrical movements, mirror and translational ones, on the dynamical asymmetry of upper limbs. As a result, the applicability of the movements under study during symmetrization was estimated. Taking into account the advantages and disadvantages of each technique and results of the study will enable us to use sufficient exercise for each person separately.

Anthropometric traits, generated forces and different modes of arm coordination differentiate genders [17, 18]. It was expected that sexual dimorphism could also be manifested in the results of the movements under study.

Material and methods

Thirty six students (15 males and 21 females) took part in the study (Tab. 1). Prior to participation, all subjects signed informed consent forms.

The first stage of the study consisted in measuring the time of swimming a distance of 15 m (in the shortest



Figure 1. The research stand

time) to determine the velocity of swimmers. Participants started from horizontal position without push-off from the wall. They swam breaststroke without kicking with a swimboard between legs.

In the second stage, recordings were taken of the force produced by the subject's upper limbs during breaststroke and front crawl simulation using a swimming ergometer (Weba, Germany) (Fig. 1). The two strain gauges were mounted between the hand pads and the ropes to measure the forces generated by each hand separately. Pulling forces, after amplifying, were recorded on a personal computer. The task of the subject was to simulate ten cycles of arms in breaststroke with the intensity equal to that performed during test in water. The first five cycles were to reach the right performance and then to sustain it. After the break participants executed ten cycles of front crawl. Force signals were recorded at 100 Hz. Then they were low pass filtered at 25 Hz. Propulsion phases of the 6th, 7th and 8th cycles of each technique were used to compute the coefficient of

Table 1. Mean and standard deviation (SD) parameters characterizing the groups tested

	Males (<i>n</i> = 15) (mean ± SD)	Females (<i>n</i> = 21) (mean ± SD)	<i>t</i>	<i>p</i>
Age (years)	21.7 ± 0.4	22.0 ± 0.6	-1.62	0.112
Body mass (kg)*	80.5 ± 9.5	57.4 ± 6.3	8.80	0.000
Body height (cm)*	181 ± 7	166 ± 6	6.78	0.000
Velocity (m/s)*	0.92 ± 0.12	0.69 ± 0.13	5.56	0.000

* level of significance was set up at $p < 0.05$, $df = 34$

dynamical asymmetry (Asym) according to the equation (adapted by the author [12]):

$$Asym = \frac{1}{N} \sum_{i=1}^N |X_{Li} - X_{Ri}|$$

$Asym$ – the coefficient of dynamical asymmetry,

N – number of samples in a cycle,

X_{Li} – force generated by the left upper limb,

X_{Ri} – force generated by the right upper limb.

Relative asymmetry (R_{Asym}) was calculated by comparing the coefficient of dynamical asymmetry with maximal force generated (F_{max}) [19].

Statistical analysis was made by Statistica package. The Shapiro-Wilk normality test was applied to examine the distribution of variables. Next a t -test was performed on each parameter in order to detect differences between the techniques and groups under investigation.

Results and discussion

The velocities measured during swimming revealed that both men and women showed moderate skills (Tab. 1) [13, 14, 20, 21]. So, selected material was adequate for the purpose of the study.

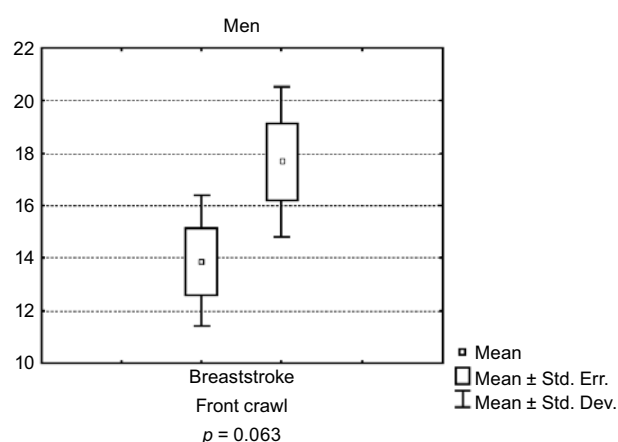
During breaststroke simulation the lower asymmetry of the upper limbs was observed for both genders (Tab. 2). It was statistically significant only for women (Fig. 2). They achieved better results than men for both techniques being studied. Probably, this was due to lower magnitudes of F_{max} generated by the females.

During daily activities translational symmetry movements are performed more often than mirror ones, for instance, in locomotion. However, lower asymmetry during breaststroke could be the benefit of programming movements with identical motor parameters [16]. In this way, the tendency of the human body towards

Table 2. Values of maximal force, dynamical and relative asymmetry for movements under study (mean and standard deviation)

	Males ($n = 15$) (mean \pm SD)	Females ($n = 21$) (mean \pm SD)	t	p
F_{max} in breaststroke (N)*	159.9 \pm 37.6	113.1 \pm 15.5	5.15	0.000
F_{max} in front crawl (N)*	164.2 \pm 26.8	111.4 \pm 17.0	7.23	0.000
Asym in breaststroke (N)*	13.9 \pm 4.9	8.7 \pm 3.1	3.89	0.000
Asym in front crawl (N)	17.7 \pm 5.7	14.7 \pm 5.9	1.51	0.140
R_{asym} in breaststroke (%)	9 \pm 2	8 \pm 3	1.32	0.196
R_{asym} in front crawl (%)	12 \pm 5	14 \pm 4	-1.04	0.305

* level of significance was set up at $p < 0.05$, $df = 34$



* level significance was set up at $p < 0.05$

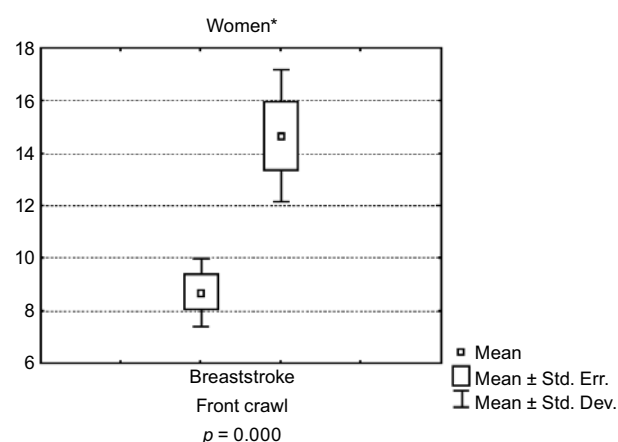
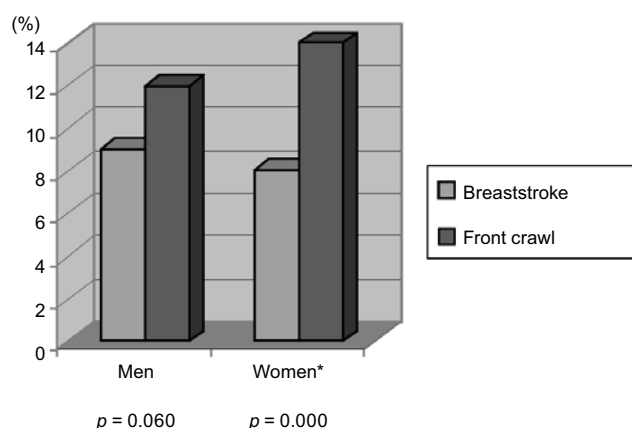


Figure 2. Dynamical asymmetry during breaststroke and front crawl for men and women

simultaneous activation of homologous muscles could be manifested. Some studies emphasize the importance of the congruency of the effects rather than symmetry of muscles or motor commands in bimanual coordination [22, 23].

On the other hand, sometimes alternative movements diminish synchronization of the motor units [24]. They offer more variable muscle activity and a greater number of torque strategies in performing movement [25, 26]. During alternative movements limbs might have manifested small differences. Such changes are imperceptible even to the best-trained eye but measurable by the strain transducers. They can be caused by the different limb velocities or trajectories as a result of the changes in the synergist and the agonist activity [27, 28]. Some studies point to inability of the central nervous system to achieve maximal activation motor units due to dispersion of the neural activity to both limbs during bilateral movements [29, 30]. In addition, during the front crawl the hand's trajectory is longer. So, front crawl provides the better opportunity to perform asymmetrical movement than breaststroke.

There were statistically significant differences in generated maximal force between the groups under study (Tab. 2.). Therefore, relative asymmetry coefficient was used to compare the asymmetry between them. It should be emphasized that F_{\max} magnitudes were similar within groups. It means that intensity of breaststroke and front crawl simulation was comparable but not maximal. Maximal activity would induce higher F_{\max} in alternative movements [29].



* level of significance was set up at $p < 0.05$

Figure 3. Relative dynamical asymmetry during breaststroke and front crawl for men and women

Taking into account the differences between genders in maximal force, R_{Asym} revealed higher dynamical symmetry in breaststroke for women. This agreed with Filon's results [31], who observed higher accuracy in female swimmers. Translational symmetry movements caused bigger problems to women as the magnitude of asymmetry was higher than for the men (Fig. 3). Although alternative movements are thought to be more natural they are more complicated for the central nervous system [16]. This task could be more difficult for women due to their lower spatial ability resulting from the different organization of brain hemispheres [32]. During the front crawl each upper extremity disappeared from view and this could cause some problems in motor control. Barrett et al. [33] observed that gender differences emerged only when participants performed movements with high velocity. He claimed that women were less able to adjust to perturbation at high intensity. During the front crawl simulation frequency of movements could be higher. This was the situation that the greater degree of biological stress may reflect a reduction in control of movement [34].

The present study was performed on swimming ergometer. Therefore, it is not known how the results of this study generalize to water locomotion, although one would expect similar results. To be sure they should be repeated during swimming. Despite this limitation, the results of the present study provide new evidence for the usefulness of mirror and translational symmetry movements to symmetrize the upper body.

Conclusions

Breaststroke movements demonstrated lower dynamical asymmetry of the upper limbs than front crawl ones both for men and women. It might appear that males can use interchangeably the two techniques during symmetrization. However, for women, first of all the mirror symmetry movements should be used.

So, selection of exercises for symmetrization of the movements of the upper limbs should be based on the gender factor, too.

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Paper received by the Editors: June 3, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence

Marcin Jaszcak
Akademia Wychowania Fizycznego
al. I.J. Paderewskiego 35
51-612 Wrocław, Poland
e-mail: jaszczak@awf.wroc.pl



POST-EXERCISE DECREASE IN HANDGRIP FORCE FOLLOWING A SINGLE TRAINING SESSION IN MALE AND FEMALE CLIMBERS*

DOI: 10.2478/v10038-008-0015-6

Jan Gajewski^{1,2**}, Bartosz Jarosiewicz¹

¹ Józef Piłsudski University of Physical Education, Warsaw, Poland

² Institute of Sport, Warsaw, Poland

ABSTRACT

Purpose. The purpose of the study was to reveal a possible relationship between maximal gripping force and climbing ability as well as to compare a decrease in handgrip force caused by training session in male and female climbers. **Basic procedures.** Seventy-four climbers (49 males and 25 females) took part in a climbing session on artificial wall. Grip force of both hands was measured twice – before and after the training session. **Main findings.** The subjects self-reported their climbing abilities in a quantitative Australian scale. In both groups, climbing ability correlated with handgrip force related to body mass. Relative force significantly decreased ($F_{1,72} = 53.2, p < 0.001$) post-exercise from 6.83 ± 1.16 to 5.96 ± 1.18 N/kg in males and from 5.43 ± 0.91 to 4.94 ± 0.84 N/kg in females. The decrease was significantly greater in male climbers ($F_{1,72} = 4.11, p < 0.05$). **Conclusions.** Less decrease in strength post-climbing in female can positively affect their climbing ability and compensate lower relative handgrip strength. Women should draw more attention to maximal strength training while men to climbing technique and endurance.

Key words: climbing, handgrip, fatigue

Introduction

Rock climbing has gained in popularity and has been recognized as a competitive sport by the International Olympic Committee [1]. The International Federation of Sport Climbing (IFSC) was set up in 2007 as a continuation of the International Council for Competition Climbing which had been in existence since 1997. The IFSC was established in order to regulate competition climbing to meet Olympic Games requirements. Compared to other sports, little research has been done on sport climbing; however biomechanical and physiological approaches have been intensified in recent years [2–4].

Rock climbing demands extreme engagement of the upper extremity muscles, especially finger flexors. Sustained and intermittent isometric forearm muscle contractions provide upward propulsion and balance keeping, especially on overhanging routes [5, 6]. A level of the relative strength of these muscles is a factor limiting climbing performance, since a climber must support

and lift his/her body acting against a body weight. Prolonged contractions at maximal and submaximal level cause a significant loss of strength as a result of growing fatigue [1, 7]. During one training session climbers usually make several ascents. It can be assumed that they choose routes due their individual climbing abilities. The aim of the study was to reveal a possible relationship between maximal gripping force and climbing ability as well as to compare decrements in handgrip caused by training session in male and female climbers of various climbing abilities.

Material and methods

Seventy-four climbers (49 males and 25 females) volunteered to participate in the study. Characteristics of the groups tested are presented in Tab. 1.

The subjects self-reported their climbing abilities as a grade of the most difficult ascent they have ever made. Climb grade was expressed in a quantitative Australian scale. Each subject took part in a ninety-minute climbing session on artificial wall. Grip force of both hands (dominant and non-dominant) was measured twice – before the training session and after the last climb while

*The study was supported by AWF grant DS-96

**Corresponding author.

Table 1. Characteristics of male and female climbers participating in the study

Variable	Males (<i>n</i> = 49)		Females (<i>n</i> = 25)	
	Mean \pm SD	Range	Mean \pm SD	Range
Age (years)	27.4 \pm 7.6	16–48	25.4 \pm 7.2	16–47
Body mass (kg)	74.6 \pm 8.6	66–93	55.6 \pm 6.0	43–65
Body height (cm)	178.5 \pm 6.8	166–198	167.0 \pm 5.1	160–180

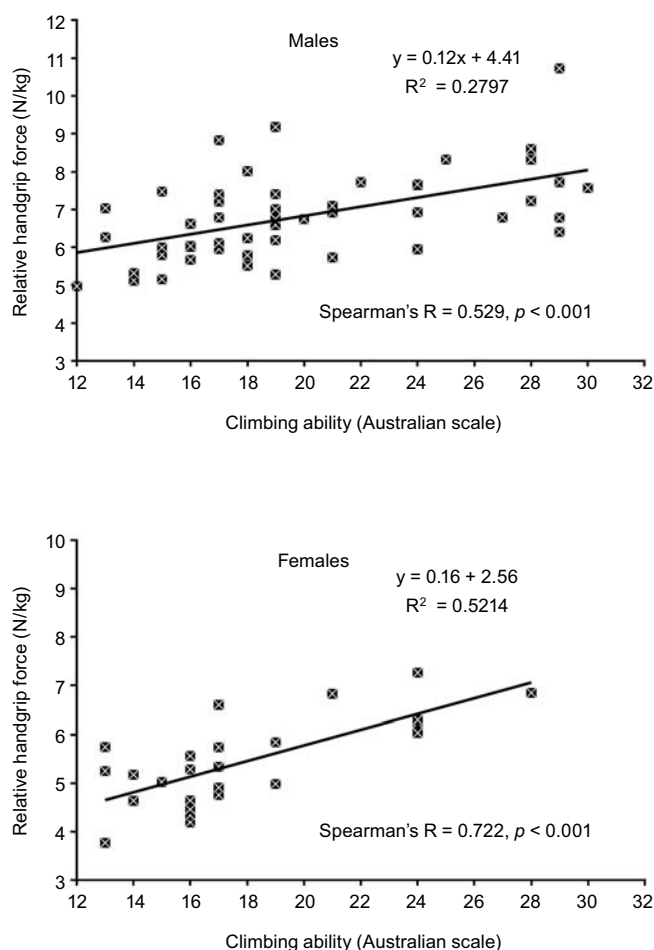


Figure 1. Relationships between climbing ability (expressed in Australian scale) and relative handgrip force (measured before a training session) in male (*n* = 49) and female (*n* = 25) climbers tested

subjects were leaving the training hall. Measurements were done in standing position using hydraulic hand dynamometer. Subjects made two attempts for each hand, and the highest reading was taken for further analysis. Handgrip forces were related to body mass. Spearman's correlation was used to evaluate relationships between variables. The U-Mann-Whitney test and the three-way ANOVA for repeated measures were utilised for the comparison of means. Grouping factor of GENDER (male and female) and repeated factors of

HAND (dominant and non-dominant) and MEASUREMENT (before and after training session) were taken into consideration. Significance level was set at $\alpha = 0.05$.

Results

The climbing ability (expressed in a quantitative Australian scale) in males did not differ significantly from that in females (20.00 ± 5.07 and 17.84 ± 4.08 , respectively). In both groups climbing ability was correlated with relative handgrip force (Spearman's $R = 0.529$ and 0.722 , for males and females, respectively). Relationship between climbing ability and relative handgrip is presented in Fig. 1.

The ANOVA for repeated measures confirmed obvious significance of main effects: difference between the relative handgrip force measured in dominant and non-dominant hand (effect HAND: $F_{1,72} = 63.02$, $p < 0.001$) as well as the difference between the handgrip in male and female (effect GENDER: $F_{1,72} = 23.55$, $p < 0.001$). The mean relative force (averaged for both hands) decreased significantly (effect MEASUREMENT: $F_{1,72} = 53.2$, $p < 0.001$) post-exercise from 6.83 ± 1.16 N/kg to 5.96 ± 1.18 N/kg in males (13%) and from 5.43 ± 0.91

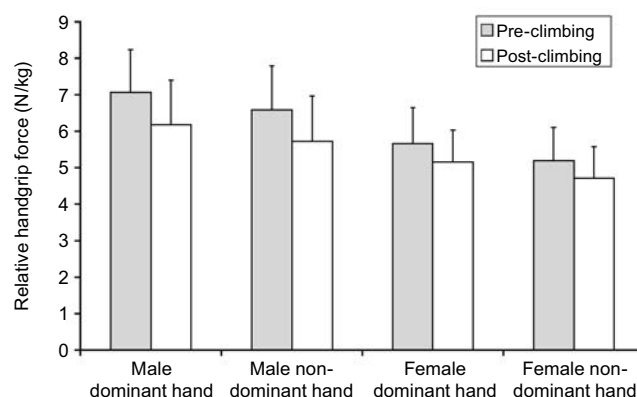


Figure 2. Mean (\pm SD) handgrip forces in male (*n* = 49) and female (*n* = 25) climbers registered for dominant and non-dominant hand before and after the climbing session

to 4.94 ± 0.84 N/kg in females (8%). Moreover, the decrease in relative force was greater in male than in female climbers (interaction GENDER x MEASUREMENT: $F_{1,72} = 4.11$, $p < 0.05$). There were no effects of interaction between HAND and MEASUREMENT ($F_{1,72} = 0.074$, p n.s.) as well as HAND and GENDER ($F_{1,72} = 0.005$, p n.s.). Mean (\pm SD) handgrip forces are presented in Fig. 2.

Discussion

It has been shown that climbing ability correlates with relative handgrip strength, which is in line with literature [2, 7]. According to the opinions presented in the literature it can be even stated that climbing ability depends on maximal strength of forearm muscles. However, some authors do not recommend handgrip dynamometry for strength evaluation in climbers [4] since it lacks specificity to climbing. However, handgrip measurements were used in the present study because of their simplicity and accuracy. A significant decrease in handgrip strength following climbing performance was also reported by other authors [1, 8]. Studies on climbing that have measured handgrip maximal voluntary contraction have produced equivocal results. Watts et al. [8] reported even a 22% decrease in handgrip strength after lead climbing. In that study handgrip force continued to be lower than resting values 20 min after the climb. In the present study, the decrements were lower (13% and 9% for males and females, respectively), because the last measurement was not done immediately after the last ascent but while a subject got out of the training hall. The most important findings of this study concern interaction effects. It is obvious that men are stronger than women or that dominant hand is stronger than non-dominant one. Lack of interaction between effects of HAND and MEASUREMENT means that there is no evidence that climbers' dominant and non-dominant hands get unequally fatigue during performance.

Interaction between GENDER and MEASUREMENT means that average decrease in handgrip was different in male and female group. As the decrease in handgrip is a sign of fatigue, one can conclude that women were less fatigued. Climbing ability of women participating in the study did not differ from that of men, while relative handgrip of women was significantly lower than that of male climbers. This may indicate that women use climbing technique in a more effective way.

It is known [9] that male climbers, especially young ones, rather tend to use more strength while solving the climbing problems. This may cause injuries, because the greater the exposure to overloading, the greater the likelihood of sustaining hand injuries [10, 11]. Dramatic loss in handgrip force restricts the climbing ability, as well, which cannot be neglected from the safety point of view. Less decrease in strength post-climbing in female can positively affect their climbing ability and compensate lower relative handgrip strength. It appears that there should be a different focus in men and women as regards climbing training. Women should draw more attention to maximal strength training while men to climbing technique and endurance.

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Paper received by the Editors: June 25, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence

Jan Gajewski

Akademia Wychowania Fizycznego Józefa Piłsudskiego

ul. Marymoncka 34

00-968 Warszawa, Poland

e-mail: jan.gajewski@awf.edu.pl



BIOMECHANICS OF TACTICS OF RUNNING A COURSE IN FOUR ALPINE SKIING DISCIPLINES: FIRST COURSE GEOMETRY RESULTS

DOI: 10.2478/v10038-008-0016-5

Włodzimierz S. Erdmann*, Piotr Aschenbrenner

Chair of Biomechanics and Technology, J. Śniadecki University School of Physical Education and Sport, Gdańsk, Poland

ABSTRACT

Purpose. The aim of the overall research on alpine skiing was examination of the biomechanical approach to tactics of running a course. The aim of this particular paper was presentation of first results on the geometry of courses of four disciplines. **Basic procedures.** The research covered competitions of alpine skiers during the 2006/2007 FIS World Cup. All four alpine skiing disciplines, i.e. downhill, super giant, giant slalom, and slalom, were taken into account. Each discipline was studied three times: in Italy, Austria, Germany, Slovenia, and Norway. 54 to 82 alpine skiers took part in each of the competitions. Differential GPS for geometry of gates setting and video camera for time data were used. Then the distribution of velocity for each runner along the entire course was calculated. **Main findings.** The first data on geometry of the ski courses revealed a large difference in vertical drop and length between the disciplines, with the angles of inclination, however, being similar. **Conclusions.** The knowledge of detailed geometry of ski courses is important since up to one-third of competitors do not finish particular runs. It happened that as many as ten skiers ran off the course at the same gate.

Key words: alpine skiing, downhill, super giant, giant slalom, slalom, tactics, geometry, course

Introduction

Good sport results in alpine skiing depend on skiers' general fitness preparation, technical skills as well as the quality of equipment, suits and waxing. A very important component of the final success is also proper course running tactics.

The course running tactics expressed in biomechanical quantities include: (a) choice of course line between the gates (optimization of the course run); (b) choice of running technique, accounting for relief of the trail and snow conditions (minimization of air drag and snow friction); (c) choice of proper velocity at particular sections of the course regarding the course geometry; and (d) distribution of velocity along the entire course (to complete and endure the run in the most efficient way possible, without running off the trail, hitting the poles, or sustaining injuries). According to Weibel [1] the most challenging elements of the course for alpine skiers are steepness, small offsets between the gates, sinusoidal sections of the course (angles of deviation) and changes of the running rhythm. Unfortunately, the concept of

velocity distribution, although significant, has been rarely subject to serious research. Having consulted top FIS World Cup trainers and skiers the authors noted their general negligence of tactical aspects of velocity distribution along the entire skiing course.

At the turn of the 20th and 21st centuries course running in alpine skiing was fragmentarily studied. The aspects researched included inter-gate way, centrifugal forces, the influence of body build on running, technique of running and forces between the ski boot and the binding as well as between the ski boot and the ski [2–5].

Erdmann et al. [6–11] studied the setting of gates along the giant slalom course and velocity distribution along the entire course. Their investigations were made with the use of measuring tape applying the triangulation formula, and with a goniometer for measuring the angles of inclination. Other studies used a theodolite (a surveying instrument). The time of course completion as well as inter-gate times were obtained from the video footage from the camera positioned at the finish area of the FIS World Cup courses. Then the velocity and its distribution along the entire course were calculated. The data obtained was used for assessment of all skiers' course running tactics. It was observed that

*Corresponding author.

a number of skiers raced too actively at the initial parts of the course. They gained some better time initially but finished later, ran off the trail or failed to complete the run.

The general purpose of our research was to examine the biomechanics of tactics of running an alpine skiing course in four disciplines: downhill (DH), super giant (SG), giant slalom (GS) and slalom (SL). The present paper reveals the first results on the geometry of skiing courses.

Material and methods

The study sample consisted of skiers taking part in the 2006/2007 FIS World Cup. 54 to 82 alpine skiers took part in each discipline. Each of the four alpine skiing disciplines was examined three times: in Selva Gardena/Wolkenstein (Val Gardena/Gröden) and La Villa (Alta Badia) in Italy, Hinterstöder (Austria), Garmisch-Partenkirchen (Germany), Kranjska Gora (Slovenia) and Lillehammer-Kvitfjell (Norway).

The setting of the gates on all the skiing courses under study was examined using the Differential Global Positioning System (DGPS), with one fixed GPS reference station and the other placed at every pole around which a given skier made his turn. The accuracy test of DGPS carried out from a ski lift registered the course run in a straight line. Additionally, the video footage of each skier's run from the big broadcast screen at the finish area was used for analysis. The video recording yielded data on skiers' times while passing next to consecutive gate poles. The obtained inter-gate times and distances allowed calculating the mean velocity between the gates as well as assessing the tactical distribution of velocity along the entire course.

Results

The study results concerning the geometry of selected alpine skiing courses revealed great differences in the length and vertical drop of the courses. Fig. 1 presents a comparison of the skiing courses under study (top view). The curve shows a set of distances between the gates. Fig. 2 presents a sample course with the setting of gates around which the skiers made their turns. Fig. 3 shows a comparison of profiles of courses of the four skiing disciplines, formed by descent lines running through the gates. A sample profile and its axonometric projection showing the setting of the gates are shown in Fig. 4.

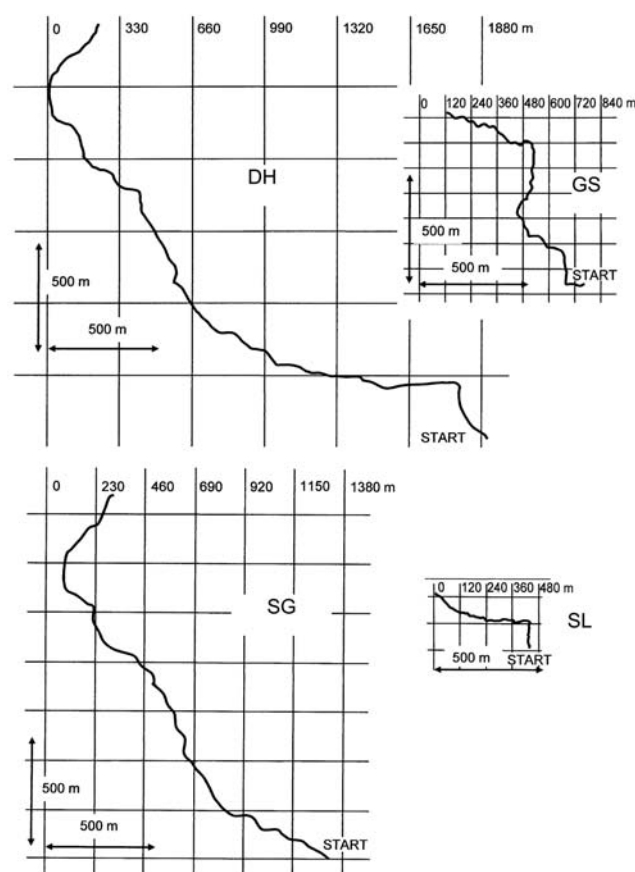


Figure 1. Sample views of courses of four alpine skiing disciplines: DH – downhill, SG – super giant (Val Gardena, Italy), GS – giant slalom, SL – slalom (Alta Badia, Italy)

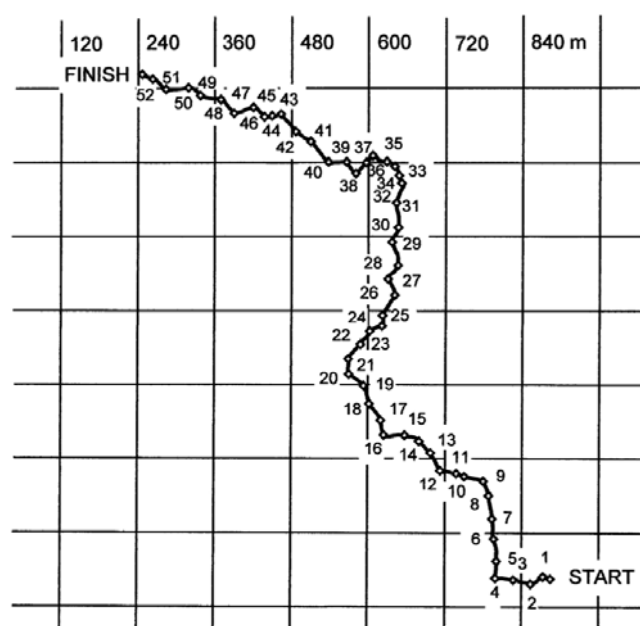


Figure 2. Sample setting of gates on the slope – giant slalom, Alta Badia (Italy)

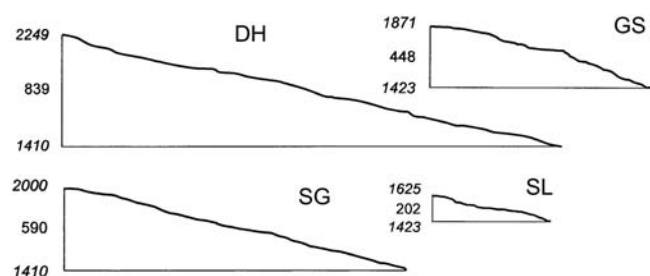


Figure 3. Comparison of course profiles (setting of gates) of four alpine skiing disciplines: DH – downhill, SG – super giant (Val Gardena, Italy), GS – giant slalom, SL – slalom (Alta Badia, Italy)

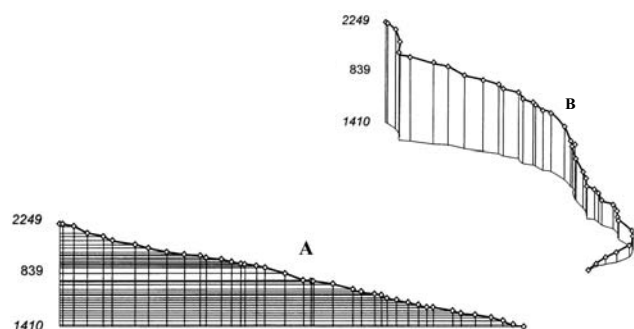


Figure 4. Sample profiles of course runs (Val Gardena, Italy) and the setting of gates: A – descent curve, B – axonometric projection

Discussion

The organizers of alpine ski competitions provide information about the elevation of the course start and finish as well as about slope characteristics. These data enabled calculation of the vertical drop. They also give information about the length of the course, however without the geometry of gates setting. Detailed knowledge about the geometry of a ski course, which accounts for the setting of the gates, in particular, about the setting of turning poles can definitely contribute to skiers' faster completion of the run. The organizers usually allow trainers and skiers to get acquainted with the geometry of the course and gates for one hour before the competition. Unfortunately, a configuration of several dozen gates is difficult to remember, thus it happens that about one-fourth or even one-third of participating skiers fail to complete the run. The run completion can be also affected by skiers' improper distribution

of physical effort. As Aschenbrenner [12] observed in his study of alpine skiers during the Winter Olympic Games in Lillehammer, competitors who had the best times after covering one-fourth or one-third of the entire distance, were not able to maintain the same level of activity until the end and finished their runs with much worse times.

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Paper received by the Editors: July 9, 2008.

Paper accepted for publication: August 28, 2008.

Address for correspondence

Włodzimierz S. Erdmann
Katedra Biomechaniki i Technologii
Akademia Wychowania Fizycznego i Sportu
ul. Kazimierza Górskiego 1
80-336 Gdańsk, Poland
e-mail: werd@awf.gda.pl



THE STRUCTURE OF ONTOGENETIC DISPOSITIONS IN YOUNG VOLLEYBALL PLAYERS – EUROPEAN CADET VOLLEYBALL CHAMPIONS

DOI: 10.2478/v10038-008-0017-4

Edward Superlak

University School of Physical Education, Wrocław, Poland

ABSTRACT

Purpose. Proper multi-level selection of talented youth is one of the fundamental aspects of qualified sport. The common autotelic approach to selection in sport, based on the measurement of individual traits and abilities and excluding any pragmatic aspects of different sports seems highly insufficient today. Each specific sport features its own factors affecting athletes' development and constituting important selection criteria. Thus, a heterotelic approach accounting for the specificity of different sports allows ontogenetic profiling of young talented athletes in view of their dispositions to act under varying circumstances. **Basic procedures.** The presented theoretical model of holistic perception of playing dispositions was verified by way of interdispositional identification of candidates for the Polish national team, who after a two-year training won the European championship in cadet volleyball. **Main findings.** The data obtained showed that each player featured a specific structure of traits and abilities understood as volleyball playing dispositions. It is assumed that individual dispositions can be – under different circumstances and to a different extent – combined into more complex structures called interdispositions. **Conclusions.** The exemplification of the theoretical model showed that playing dispositions could and should be studied in an interdisciplinary manner. The holistic approach to the player's individual traits makes his or her profiling more comprehensive, which affects the development of skills and performance assessment methods.

Key words: volleyball, talents, dispositions, interdispositions

Introduction

Modern qualified sport involves constant improvement of effectiveness of the process of athletes' training and obtaining high sport results. The modern scientific and technological development allows this process and facilitates solving practical problems in sport.

One of the most fundamental issues in contemporary sport is the search for the most effective means of selection of future athletes. The process of selection should account for proper differentiation between athletes and correct identification of the most outstanding candidates for further training leading to the championship level.

A number of earlier studies concerning selection in sport [1–3] focused on the so-called “championship model” for particular sports. By way of observations and examinations of sport champions the authors defined athletes' major traits and qualities. They assumed that achieving the critical values of the “championship model” was necessary and entirely sufficient to ensure

success in sports competition. This assumption can be accepted in some sports, e.g. individual sports, but not in team sports, where cooperation and interaction in changing situations as well as social and organizational effects are involved. The championship model approach excludes the phenomenon of “equifinality” thanks to which players with different structures of traits, abilities and talents achieve similar sports results.

Ontogenetic identification of children and adolescents with abilities or talents for sports from the autotelic standpoint has been subject to numerous research studies in the areas of anthropomotrics or psychology [4–10]. According to Panfil [11], if significant correlations between a trait or ability and effectiveness of action are observed, then such traits or abilities are understood as dispositions to practice a given sport. An important aim of studies facilitating solution of problems in modern sports is the heterotelic approach which highlights young players' predispositions, dispositions and interdispositions specific for a given sport (Fig. 1).

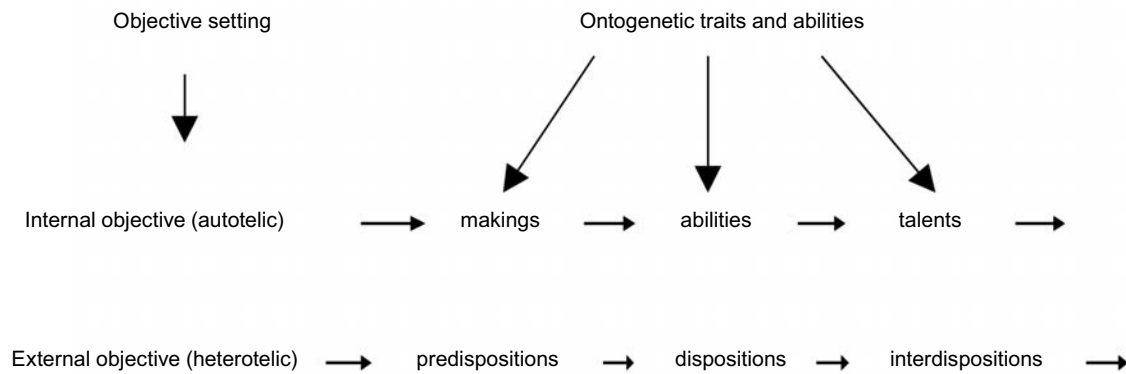


Figure 1. Ontogenetic traits and abilities and objective setting

The holistic model of sport playing dispositions

The understanding of factors conditioning the achievement of objectives in a team game is possible with the aid of a number of relatively isolated sciences (each featuring its own axiology, research methodology and language). However, sciences which do not make up for a synergy of knowledge, fail to yield a multi-factor analysis of player's actions. Thus, an interdisciplinary and systemic approach seems more reasonable. Such an approach, according to Panfil [11], relies on the cooperation of representatives of different sciences on the model of mutual relationships between playing dis-

positions and situations during a game, which indicate the player's skills to act. The model of playing interdispositions, based on the player's individual traits and abilities displayed in changing game situations was suggested by Superlak [12] (Fig. 2).

Adopting Panfil's postulates of praxeology of sports games [13] two concepts: dispositions and interdispositions can be applied. Since the player's body is a coherent, complex and dynamic entity, the player's particular ontogenetic dispositions can form an interdisposition. According to Panfil [13] interdisposition is an arrangement of interrelated ontogenetic dispositions, which leads to formation of a new quality, which is not a mere

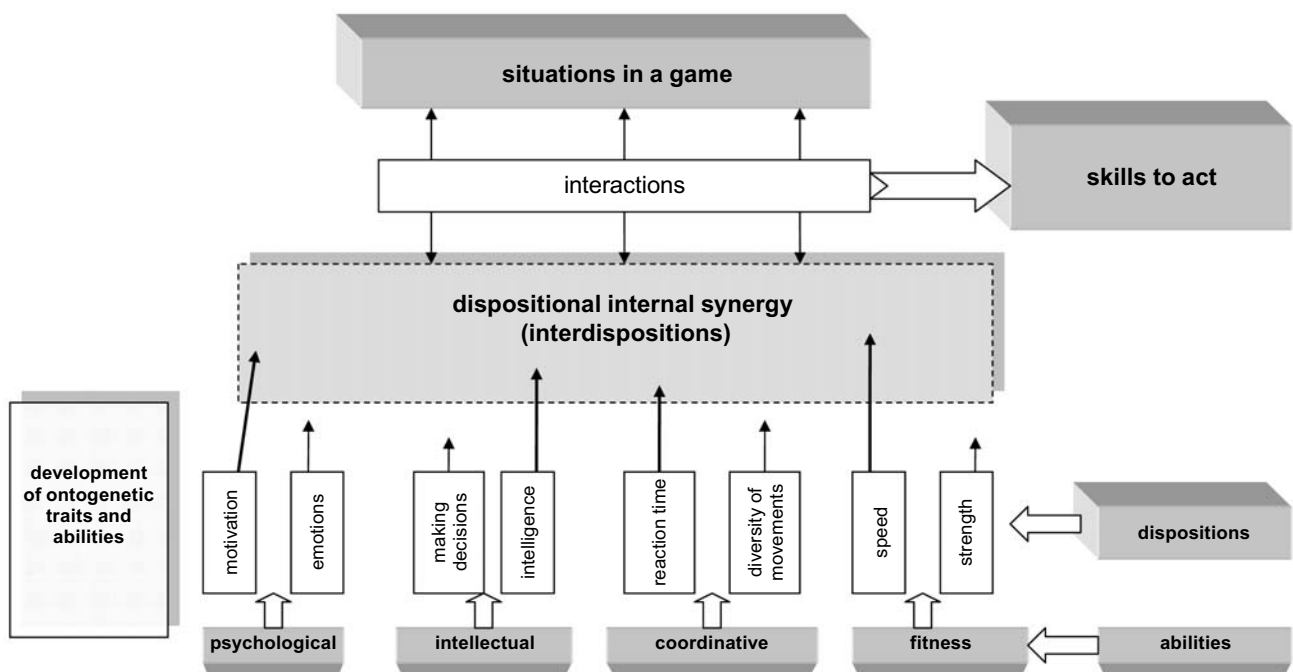


Figure 2. Simplified hypothetical model of dispositional synergy affecting the player's skills in a game

direct sum of the constituent dispositions. Interdispositions are formed through internal synergic effects related to players' psychophysical capabilities.

On the basis of existing research literature as well as the author's own long-term coaching and research experience an original model of identification of volleyball playing dispositions was developed, which accounted for the holistic approach to factors conditioning playing skills. The aim of the study was to exemplify a theoretical model based on the identification of individual dispositions of young volleyball players who won the European Cadet Volleyball Championship.

Material and methods

The research sample consisted of 12 volleyball players, aged 15 years, who had been selected for the Polish national team (out of 1500 candidates from all over Poland), following a two-year training and a multi-stage selection process. Considering the specificity of volleyball as well as the level and range of specific player's skills conditioned by the player's structure of ontogenetic dispositions, the national team coach made particular players take the positions of setter, center and receiver.

The following tests were used for identification of the young volleyball players' dispositions:

- somatic features – body height (cm), body mass (kg), one-arm's reach in a standing position (cm) and two-arm reach in a standing position (cm);
- fitness test – running jump with one arm up (cm), standing jump with both arms up (cm), dynamic force – overhand 3-kg medicine ball throw, speed test – 10-m run (s), locomotive speed – running with a direction change (envelope run) (s);
- coordination skills test – speed of psycho-motor responses to visual signals [13];
- test of specialist knowledge [14]; test of intellectual potential [15].

The tools for measurement of somatic parameters and fitness, which have been used for research for several years, were selected by a team of outstanding volleyball experts appointed by the Department of Training of the Polish Volleyball Association. They were standardized using the precise descriptions of measurement conditions and tests.

The low, average and high results of different variables (measured on different scales) were compared using standardized results. The results with higher than average values (above one or two standard deviations) have been set in bold in Tab. 1.

Table 1. Ontogenetic profiles of 15-year-old volleyball players – candidates for the Polish national cadet volleyball team

Traits and abilities	Players (positions on the court)											
	Receivers						Centers		Setters			
	Ś.J.	G.M.	S.B.	Ja.B.	B.Z.	K.M.	Ch.M.	S.M.	K.W.	J.B.	Ł.G.	K.P.
Body height (cm)	187	188	187	185	190	202.5	190	197	191	191	179	184
Body mass (kg)	77	70	74	65	69	89	80	90	70	63	69	68
Rohrer's index	1.13	1.05	1.13	1.03	1.01	1.07	1.17	1.18	1	0.9	1.2	1.09
One-arm's reach (cm)	248	252	242	246	254	265	258	262	250	254	237	242
Two-arm reach (cm)	246	247	238	241	250	260	252	256	248	251	234	138
Running jump (cm)	330	321	317	317	331	330	317	325	316	314	312	295
Standing jump (cm)	306	295	302	303	310	315	303	310	296	302	295	282
Jumping ability (running) (cm)	82	69	75	71	77	65	59	63	66	60	75	53
Jumping ability (standing) (cm)	60	48	64	61	60	55	51	54	48	51	61	44
Dynamic force of shoulder girdle muscles (m)	8.5	7.9	9.4	10.8	7.9	7	9.3	11	9	7.7	8.8	7
Envelope run (s)	13.89	15.15	14.54	14.08	15.08	15.25	15.55	15.72	16.09	15.42	14.38	15.53
10-m run (s)	1.78	1.77	1.61	1.54	1.59	1.81	1.84	1.69	1.72	1.73	1.6	1.72
Psychomotor response time (s)	19.78	9.16	17.08	12.36	22.44	14.19	10.26	10.52	12.48	18.73	12	10.19
Test of specialist knowledge (%)	39.54	40.08	28.2	36.16	40.53	25.28	37.43	14.28	46.44	23.28	40.03	34.13
Answer time of specialist knowledge test (min)	5.54	5.08	5.2	6.16	6.53	6.28	6.43	5.28	6.41	6.28	7.03	6.13
Test of intellectual potential	100	85	115	102	100	65	100	92	105	100	110	125
Answer time of intellectual potential test (min)	10.35	7.1	8.27	7.32	7.34	11.3	9.35	5.08	9.33	7.2	7.13	9.15

Results

Empirical verification of the theoretical model

The young players under study were characterized in terms of their volleyball playing dispositions and skills in the somatic, motor and intellectual spheres. Each player featured a compilation of dispositions and abilities constituting specific ontogenetic structures. Only in the case of somatic structure did all subjects feature a leptosomatic body build. All the centers featured above the average body height, which is a basic criterion of selection for players in this particular court position (Tab. 1).

The results obtained show that the majority of subjects (eight players) featured a high level of specialist knowledge, but only few (two players) reached high results in the test of intellectual potential. Apart from the variables mentioned above the main factors affecting the players' intellectual potential include the speed of situation assessment and decision making: above the average task-solving times were obtained by four players (specialist knowledge test) and one player (intellectual potential test), respectively.

In accordance with the theoretical model, it can be noted that better than average results obtained by the young volleyball players constitute their playing dispositions, whereas the relationships between them constitute playing interdispositions determining the level of action play displayed by the European champions.

Each subject featured a certain number of individual variables at a level better than average, which can be classified as somatic, fitness and intellectual. Using a qualitative ordering of the variables under study and their correlations the following interdispositions were identified: somatic-intellectual, fitness-intellectual and somatic-fitness-intellectual.

In two cases the individual variables constituted the same disposition category. The dispositions with better than average values (above one standard deviation) can be considered to be a somatic-intellectual interdisposition (Tab. 2–4).

Discussion

The foundation of good selection in sport is seeking – using rational criteria – young people holding promise of their effective development of skills and abilities. Each sport requires specific traits and abilities which

Table 2. Interdispositional profiles of volleyball players (centers) – members of the Polish National Cadet Volleyball Team

Player	Dispositions	Interdispositions
S.M.	somatic fitness intellectual	somatic–fitness–intellectual
K.W.	somatic intellectual	somatic–intellectual
J.B.	somatic	–

Table 3. Interdispositional profiles of volleyball players (receivers) – members of the Polish National Cadet Volleyball Team

Player	Dispositions	Interdispositions
Ś.J.	somatic fitness intellectual	fitness–intellectual
G.M.	somatic fitness intellectual	somatic–fitness–intellectual
S.B.	fitness intellectual	fitness–intellectual
Ja.B.	fitness intellectual	fitness–intellectual
B.Z.	somatic fitness intellectual	somatic–fitness–intellectual
K.M.	somatic fitness	somatic–intellectual
Ch.M.	somatic fitness intellectual	somatic–fitness–intellectual

Table 4. Interdispositional profiles of volleyball players (setters) – members of the Polish National Cadet Volleyball Team

Player	Dispositions	Interdispositions
Ł.G.	fitness intellectual	fitness–intellectual
K.P.	intellectual	–

significantly determine the development of top level athletes. Thus the process of ontogenetic identification of young athletes should involve a heterotelic approach aimed at a multi-level selection of the most talented individuals from the vantage point of a given sport.

Somatic features and motor skills required in volleyball have been subject to a number of research studies [12, 16–18]. Klocek and Żak [19] propose that the main factors determining effectiveness of action in volleyball are speed-strength abilities and speed abilities. It is highly significant that the results of numerous studies on selection of players in volleyball have been used in the volleyball coaching practice in Poland.

Any action during a game involves a conscious or spontaneous choice of alternatives based on the player's intelligence and the level of specific knowledge about the game [20] which improves with the player's sport experience [21]. Miedzińska [22] in her study proposed a correlation between reaction time and the level of general intellectual ability. According to her, "faster" individuals feature a higher IQ than "slower" ones. A similar observation was made by Nęcka [23], who revealed that more intelligent people featured a greater speed and volume of information processing. These results show that reaction time can be a significant indicator of better intellectual capacity. A player's level of specialist knowledge about the game as well as his or her experience gained during competition affect, according to Naglak [24], the development of a specific perception which enables the player's functioning in dynamic and constantly changing situations during the game. The perception of a situation is based on such intellectual functions as understanding, anticipating, assessing and concluding.

The proposed model of holistic approach to volleyball playing dispositions was verified in the process of ontogenetic identification of young volleyball players who won the European championship in cadet volleyball. Using Panfil's praxeological criteria of interdisciplinary ontogenetic assessment of athletes [11], the volleyball players were characterized in view of playing interdispositions. The results obtained show that young, talented volleyball players feature diverse structures of dispositions, which may form interdispositions being synergic effects of correlations of different individual traits and abilities.

Conclusions

The interdisciplinary methodology used in research of ontogenetic determinants affecting the development of special skills is appropriate. The holistic approach to ontogenetic dispositions of individual players with diverse ranges and levels of skills and abilities validates the phe-

nomenon of equifinality in sport. Equifinality still requires a proper didactic approach, but it must not be ignored in the process of training talented individuals.

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Paper received by the Editors: April 8, 2008.

Paper accepted for publication: August 21, 2008.

Address for correspondence

Edward Superlak

Katedra Zarządzania i Coachingu

Akademia Wychowania Fizycznego

al. I.J. Paderewskiego 35

51-612 Wrocław, Poland

e-mail: edward.superlak@awf.wroc.pl



PARTICIPATION OF YOUTH IN PHYSICAL EDUCATION FROM THE PERSPECTIVE OF SELF-DETERMINATION THEORY

DOI: 10.2478/v10038-008-0019-2

Krzysztof Sas-Nowosielski

Chair of Humanistic Bases of Physical Culture, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

ABSTRACT

Purpose. The purpose of the study was to determine whether perceived competence, autonomy and relatedness are correlated with behavioral regulations proposed in the self-determination theory; and to examine effects of these regulations on the intention to fully participate in physical education lessons and on experiencing boredom during them. **Basic procedures.** The study used a cross-sectional analysis. A total of 293 middle- and high-school students took part in the experiment. Participation in the study was anonymous and voluntary. The data was analyzed using structural equation modeling (path analysis). **Main findings.** Out of the theorized psychological mediators of behavioral regulations only perceived competence and relatedness turned out to be statistically significant. Perceived competence was the strongest predictor of both intrinsic motivation (positive) and amotivation (negative). As a consequence of behavioral regulations, intention to participate was positively predicted by intrinsic motivation and negatively by amotivation, whereas boredom was negatively predicted by intrinsic motivation and positively by amotivation. **Conclusions.** To support students' intentions to fully participate in physical education classes and to reduce boredom experienced during them PE teachers should promote students' intrinsic motivation to participate in physical education. This can be possible when perceived physical competence in the PE context is supported and positive interpersonal relationships between students are promoted.

Key words: physical education, motivation

Introduction

Physical education is a universal, mandatory, systematic and curricular form of participation in physical culture. It is commonly regarded as the most important form of lifetime physical activity. However, statistics show that the effectiveness of physical education leaves much to be desired, as the percentage of adults in developed countries, who lead an active lifestyle is, euphemistically speaking, highly unsatisfactory [1]. The problem of the low level of physical activity, which is insufficient to meet the biological needs of human body, is also a serious public health problem of Polish adolescents. Woynarowska [2, 3] revealed that only 35.3% of subjects declared undertaking physical activity at the recommended level (60 min a day, 5 days a week), whereas 24% took part in physical activity at a “very low” level (0 to 2.5 days a week). Additionally, the level of participation of school youth in physical education is not always satisfactory, and some studies show that it declines along with completed levels of school education [4]. Bukowiec's research [5] showed that physical education was rarely considered to be a source of an ac-

tive lifestyle. According to Bukowiec only 33.4% of subjects admitted that they followed a physically active lifestyle because they had been inspired by their PE classes, and for more than 10% physical education at school was actually a discouraging factor to undertake physical activity. There are various reasons for such observations. Some are related to the methodological mistakes made by PE teachers who fail to identify with their own profession; some can derive from the dominant and constantly applied model of PE teaching, which stresses physical fitness and favors more physically fit students. This tendency was once described by one of the most outstanding Polish theorists of physical education as “physical education for the fittest” [6]. What follows is alienation of less able children from physical education, who are not able to find their place in PE classes imbued with competition [7]. These problems are not only characteristic of Polish schools [8].

Pedagogues and psychologists of physical culture, who seek different ways of enhancement of pedagogical effectiveness of physical education, have been taking a growing interest in application of self-determination theory (SDT) developed by Deci and Ryan [9, 10],

which has already been successfully used in other areas of school education. The assumptions of SDT can be described as follows:

1. There are a few types of motivations, known as behavioral regulations, which can be aligned along a continuum, from extrinsic motivation, through four behavioral regulations, to intrinsic motivation. This continuum reflects an increase in self-determination understood as internalization of extrinsic motives, i.e. assimilation of originally external behavioral regulations. The behavioral regulations include:

- *Amotivation* – lack of intention to undertake physical activity, often due to incompetence, lack of values supporting physical activity and failure to notice the link between undertaken actions and expected results.
- *External regulation* – identified with the traditional concept of extrinsic motivation, refers to doing something for the sole purpose of achieving a reward (e.g. a good grade) or avoiding a punishment.
- *Introjected regulation* – refers to partial internalization of extrinsic motives. It is fairly superficial and can be compared to “swallowed food which has not been yet digested” [11, p. 69]. For instance, an introjected regulation takes place when a student comes to PE classes just to avoid feeling remorse, to keep the PE teacher satisfied or to be perceived as a sports-lover by his/her peers. It is therefore an internally controllable behavioral regulation, expressed with feelings such as “I must” or “I should” [11, p. 69].
- *Identified regulation* – is undertaking an activity by an individual identifying with the values of the activity (e.g. health, fitness, body shape) to the extent that it becomes autonomous. Identified regulation is a voluntary behavior, even if the activity itself is not pleasant. It is still considered to be a sort of external regulation as regards its focus on the outcome of the activity than the activity itself (“I want to ... because I know it is important to me”).
- *Integrated regulation* – is identification with the values and meanings of the activity to the extent that it becomes fully internalized and autonomous. It is integrated with EGO and is voluntary – like identified regulation – but undertaken following one’s personal aims and values (“I exercise because I am an active person and I care about my own health”). As this type of regulation requires full development of one’s own identity, it is considered rare among children and youth. Thus integrated regulation is not diag-

nosed with research tools recommended for groups of children and youth.

- *Intrinsic motivation* – is undertaking an activity for the activity’s sake: the source of satisfaction and stimulation is the activity itself, not its results. Although intrinsic motivation does not ignore such outcomes as health, fitness or body shape, they are rather treated as the activity’s “welcome side effects” rather than its own sources.

2. The behavioral regulations in a person’s motivational profile determine the level and length of an undertaken activity. They also control the person’s feelings and convictions during performing this activity. It has been assumed that the most beneficial behavioral, cognitive and affective consequences are due to more autonomous (self-determined) types of regulations (intrinsic motivation, integration, identification). Thus, for instance, the most determined participants in physical culture are those individuals for whom the participation is a source of satisfaction and positive stimulation, and is at least perceived as the most suitable means for realization of highly significant and deeply internalized values of health, fitness and beauty.

3. Self-determination involves three psychological, intrinsic needs: need for autonomy (feeling of being free from pressure, i.e. the need to experience one’s actions as a result of autonomous choice); need for competence (i.e. the need to experience oneself as capable and competent in controlling the environment of the activity); and need for relatedness (need to experience authentic relatedness from others and to experience satisfaction in participation and involvement with the social world, e.g. with class mates during a PE lesson). The perceptions of alienation, rejection and low self-esteem in a given context are serious obstacles to deriving satisfaction from undertaking physical activity as well as to the internalization of values involved in this activity. It must be emphasized that all kinds of social contexts in which an individual functions – e.g. teaching style, motivational and emotional surroundings, character of peer relations, etc. – indirectly affect the student’s motivation by way of the abovementioned psychological needs. Therefore, how teachers teach is equally important with what teachers teach, i.e. activities during class enhance self-determined and internalized motivations and meet the demands of all students [12].

There have been several studies on potential implications of SDT for school physical education (as well as for youth and children sport), which proposed concrete

pedagogical actions (see, in particular, [13, 14]). There has also been a growing interest in the empirical verification of SDT implementation in physical education, including an interesting combination of SDT and the theory of planned behavior, known as the trans-contextual model, which describes how motivation for physical education can be used for leisure-time physical activity (see model description in [15] and its empirical implementation in [16, 17]).

The studies involving SDT have all hitherto assessed consequences of particular types of behavioral regulations as well as social factors contributing to or distorting the fulfillment of the psychological needs for competence, relatedness and autonomy. The consequences under study included the level of students' concentration of attention, positive and negative affective reactions, preferences in terms of choice of difficult tasks, intentions to undertake leisure-time physical activity, teacher's evaluation of self-evaluation of student's effort in class and intentions to participate in optional physical education classes [18–21]. The social variables examined in those studies included possibilities of choice during PE classes and motivational climate (see [22] for a review of literature on motivational climate, and [18, 23, 24] on interplay education). Without any detailed analysis of the results of these studies, it can be generally stated that all of them confirmed the theoretical assumptions.

The aim of the present study was to determine whether and to what degree perceived competence, autonomy and relatedness affect particular behavioral regulations in participation in physical education; and whether and to what degree the behavioral regulations influence the intentions to take active part in PE classes and experiencing of boredom during them? Two research hypotheses were assumed:

1. The high level of perceived competence, autonomy and relatedness is positively correlated with self-determined behavioral regulations, and negatively correlated with extrinsic motivation (external regulation).
2. An increase in self-determined regulations is related to firmer intentions to take active part in PE classes and to a much lower level of boredom experienced during them.

Material and methods

The study was carried out in Katowice, Poland at the beginning of the school year of 2006/2007. The study sample included 293 middle school and high school stu-

dents. The subjects were to fulfill an anonymous questionnaire. Cronbach's coefficient α was used to measure the reliability of the instrument. Following Sokołowski and Sagan [25] α value of 0.60 was accepted as the limit of acceptable reliability level of an instrument.

The behavioral regulations were measured using the Behavioral Regulations in Exercise Questionnaire-2 (BREQ-2), translated into Polish accounting for the specific context of the study, i.e. physical education. The questionnaire consisted of five subscales on a 5-point Likert scale, measuring five behavioral regulations: amotivation (e.g. "PE classes make no sense to me at all"); external regulation (e.g. "I take part in PE classes to keep my parents/teachers satisfied"); introjected regulation (e.g. "I take part in PE classes, because if I did not, I would feel remorse"); identified regulation (e.g. "I take part in PE classes because I value the benefits from physical exercises"); and intrinsic motivation (e.g. "I take part in PE classes because it gives me pleasure and satisfaction"). All the subscales were reliable with Cronbach's coefficient α values of 0.64, 0.72, 0.74, 0.82 and 0.83, respectively.

The determinants of regulation were measured using three sets of positions on a five-point Likert scale: from 1 ("definitely false") to 5 ("definitely true") related to:

1. perceived competence, i.e. perception of one's own motor abilities in the context of physical education (e.g. "I think I can perform even the most difficult exercises during my PE classes");
2. perceived autonomy in PE classes as a conviction about one's own choices of the ways of exercise performance (e.g. adjusting exercise intensity), co-deciding about undertaking forms of physical activity, and possibilities of resolving one's own doubts (e.g. "In my PE classes I can choose exercises I want to do");
3. relatedness, i.e. perceptions of interpersonal relationships with other students, integration with other students, involvement in class activities (e.g. "I can take part in a game during PE classes to the same extent as others").

The reliability of all the three subscales was satisfactory, with Cronbach's coefficient α values of 0.88, 0.78 and 0.79, respectively.

Consequences of behavioral regulations were examined in view of intentions to actively take part in PE classes during the current school year, and of the level of boredom experienced during PE classes. The intentions were measured on a four-point scale, preceded with the following introduction: "Decide which of the

following statements describe best your intentions to take part in PE classes during the current school year?" The statements described four possible situations: regular participation and full involvement in PE classes; regular attendance at PE classes with some involvement; regular attendance at PE classes without active participation (e.g. sitting on the bench); and getting doctor's leave and avoiding PE classes. The experience of boredom was assessed using a three-position scale developed by Ntoumanis [18] (e.g. "I am usually bored in my PE classes") with a Likert scale (1 – definitely no; 5 – definitely yes) and with Cronbach's coefficient α of 0.85.

The statistical analysis of the obtained data used path analysis with the following goodness to fit indicators: χ^2/df , RMSEA (Root Mean Square of Approximation), GFI (Goodness of Fit Index) and NNFI (Non-normed Fit Index). The acceptable goodness to fit level was at $\chi^2/\text{df} > 2$ – well fit, > 5 – acceptably fit; RMSEA < 0.08 ; GFI > 0.85 ; and NNFI > 0.80 . All calculations were made with the Statistica software package.

Results

The mean values, standard deviations and correlations between variables are presented in Tab. 1. The mean values in particular types of behavioral regulations point to a fairly moderate motivational profile of the subjects: means for identified regulation and intrinsic motivation amounted to 3.81 and 3.52, respectively, (i.e. slightly above the threshold of indecisiveness and ambivalence). In the case of psychological mediators, the highest means were obtained for relatedness (3.90) and the lowest for autonomy (3.11).

The original theoretical model (Fig. 1) assumed, first of all, a significant impact of competence, autonomy and relatedness on all behavioral regulations, with a stronger positive influence along the increase in self-determination; and second of all, an impact of all behavioral regulations on the consequences examined. Unfortunately, it failed to pass the goodness to fit test and had to be revised. The best results were obtained for an alternative model presented in Fig. 2: $\chi^2/\text{df} = 2.63$, RMSEA = 0.07, GFI = 0.88 and NNFI = 0.88. The following β ranges were applied in the analysis: $\beta = 0.10$ – 0.30 – weak relationship, $\beta = 0.30$ – 0.50 moderate relationship, $\beta > 0.50$ – strong relationship. A variable which was most strongly correlated with intrinsic motivation was perceived physical competence ($\beta = 0.68$).

Table 1. Means, standard deviations, and correlations between SDT variables

Variable	M	SD	Amotivation	External regulation	Introjected regulation	Identified regulation	Intrinsic motivation	Competence	Autonomy	Relatedness	Boredom
Amotivation	1.90	0.91	–								
External regulation	2.88	1.12	0.37*	0.37*	0.35*	–0.48*	–0.50*	–0.46*	–0.15*	–0.41*	0.39*
Introjected regulation	2.61	1.04	0.35*	0.65*	–	–0.12**	–0.21*	–0.18*	–0.08 ^{NS}	–0.27*	0.11 ^{tend}
Identified regulation	3.81	1.00	–0.48*	–0.25*	–0.12**	–	0.79*	0.61*	0.29*	0.43*	–0.34*
Intrinsic motivation	3.52	1.11	–0.50*	–0.32*	–0.21*	0.79*	–	0.59*	0.36*	0.39*	–0.45*
Competence	3.70	0.95	–0.46*	–0.22*	–0.18*	0.61*	0.59*	–	0.25*	0.41*	–0.40*
Autonomy	3.11	0.86	–0.15**	–0.12**	–0.08 ^{NS}	0.29*	0.36*	0.25*	–	0.27*	–0.25*
Relatedness	3.90	0.85	–0.41*	–0.22*	–0.27*	0.43*	0.39*	0.41*	0.27*	–	–0.20*
Boredom	2.56	1.19	0.39*	0.24*	0.11 ^{tend}	–0.45*	–0.34*	–0.40*	–0.25*	–0.20*	–
Intention	3.62	0.79	–0.43*	–0.25*	–0.21*	0.49*	0.45*	0.36*	0.21*	0.25*	–0.43*

* $p < 0.01$, ** $p < 0.05$, ^{NS} non-significant, ^{tend} tendency towards statistical significance of differences ($0.05 < p < 0.1$)

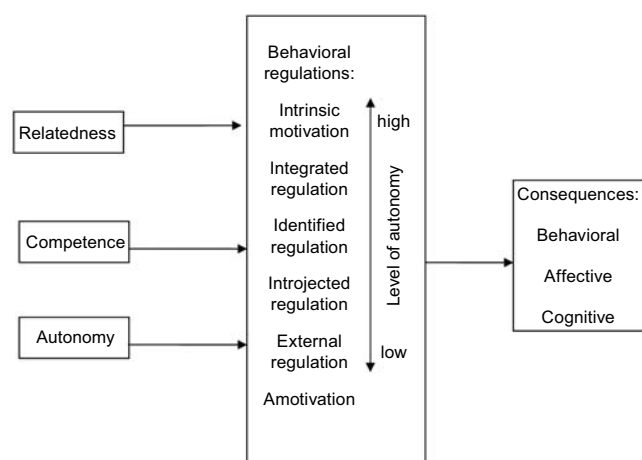


Figure 1. SDT variables and assumed relationships between them

The correlation between perceived competence and intrinsic motivation to participate in physical education can also be regarded as strong. A moderately strong and positive influence of relatedness and intrinsic motivation was also observed ($\beta = 0.17$). Both variables negatively influenced external regulation and amotivation. It can be concluded that the higher level of perception of one's competence in the context of physical education and of one's self-esteem as a member in a PE class, the lower one's inclination to be only motivated (or amotivated) by external rewards, punishments or pressure.

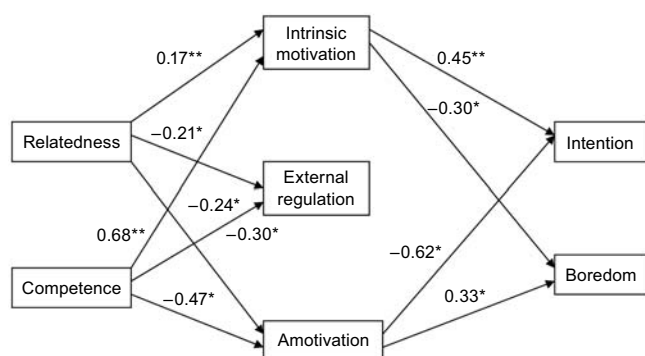
Only the correlations between the two extreme behavioral regulations, i.e. amotivation and intrinsic motivation, and the consequences were statistically significant. Therefore, as originally assumed, the intention to take part in PE classes was positively influenced by intrinsic motivation and negatively influenced by amotivation (in both cases the relationship was strong). Re-

verse correlations were noted between intrinsic motivation and boredom (moderately negative), and amotivation and boredom (moderately positive). It means that the less sense in taking part in PE classes students see (due to their perception of incompetence or lack of fulfillment of affiliative needs), the more boring they find them. On the other hand, those for whom PE classes are a source of satisfaction are far less inclined to get bored during them.

Discussion

SDT is regarded as one of the most promising theoretical approaches to the study of motivation of school children and youth, which has already yielded numerous methodological indications for teachers [26]. One of the contexts of such research is school physical education, which should play an important role in propagation of physical activity at large, but it constantly faces the problem of students' reluctance to take part in PE classes or participating in PE classes "under coercion."

The aim of this study was to determine whether and to what extent perceived competence, autonomy and relatedness affect different types of behavioral regulations to participate in physical education, and whether and to what extent the behavioral regulations have an impact on intentions to actively participate in PE classes and experiencing negative affective reactions (boredom) during them. Both research hypotheses have been partially confirmed by the results of this study. The obtained model of causal relationships revealed that the theoretical behavioral regulations which were statistically correlated with theoretical predictors and/or consequences included only amotivation, external regulation and intrinsic motivation. The most significant factors affecting behavioral regulations turned out to be perceived physical competence and relatedness, i.e. the perception of being a respected and acceptable, full-fledged member of a class. What was surprising was the fact that the revised model of relationships between SDT variables failed to include autonomy, whose role had been emphasized by the authors of self-determination theory [9, 10]. The obtained results might be a reflection of the relatively low popularity of activities aimed at enhancement of student autonomy in Polish schools. This was also noted earlier by an international research team led by Hagger et al. [16] in their cross-cultural study on youth from the UK, Greece, Poland and Singapore, using the trans-contextual model. They



* $p < .01$, ** $p < .05$

Figure 2. Revised model of relationships between SDT variables and affective reactions and intentions

observed that only among the Polish youth the perceived autonomy support had no effect (direct or indirect) on their autonomous leisure-time motives, and that the level of perceived autonomy support was far lower in the Polish population sample as compared with the others. Another explanation was offered by Ntoumanis [18], in whose study perceived autonomy was shown to be only a weak predictor of external regulation ($\beta = -0.12$); while the strongest predictor of behavioral regulations was, like in the present study, perceived competence, which had a positive and significant influence on intrinsic motivation and identified regulation, a strong but negative impact on amotivation, and moderate, negative impact on external regulation. Ntoumanis [18] referred to the lack of autonomy support during PE classes, but also to the fact that the relative significance of each psychological predictor of behavioral regulations depended on their functional significance in a given situation. Since perceived physical competence plays a crucial role in many forms of physical activity, including physical education, those who evaluate perceived physical competence at a high level will be more inclined to perceive physical education as interesting, pleasant and satisfying, and will be more intrinsically motivated to participate in physical education, regardless of perceived autonomy.

The obtained results point to the necessity to organize classes in such a way as to provide all students with a subjective conviction that their current level of physical abilities (endurance, motor, learning, etc.) is enough for them to be competent students. This can be achieved, for instance, by development and enhancement of the definition of success based on auto-reference criteria among the students. The significance of this cognitive approach and the possibilities of its development through creation of a proper motivational climate in PE and sport classes were thoroughly researched in a study based on the theory of achievement motivation by Nicholls [27]. He showed that individuals with high task-oriented motivation (i.e. people who in their assessment of their own competences and successes follow, first of all, auto-reference criteria, focus on their personal development and do not care about their position with reference to others) feature better adaptability and have more opportunities to experience positive affective reactions than individuals with a high ego (i.e. those who define success and their own competences through normative criteria and relatedness to other people's results). Thus, the so-called championship motivational climate, which

primarily propagates task orientation, should be created in PE and sport classes [28]. This model does not exclude elements of competitiveness, providing they are incorporated in such a way that they do not lead to the elitism of competences among students, reserving them for the fittest ones and leaving others out in their conviction they are unfit for physical culture. A consequence of low perceived physical competence is reluctance toward physical education.

The variable of relatedness, related to the level of fulfillment of affiliative needs, had a weak positive impact on intrinsic motivation, a weak negative impact on external regulation and moderate negative impact on amotivation. These results show that the more students feel they are not able to compete with their team mates in sport games, are excluded from playing on the most attractive positions on the pitch and are not able to count on their class mates for help, the higher level of amotivation they experience. A partial solution to this problem, in order to make students like PE classes more and participate in them more often, is to treat all the participating students in the same way during a game. Although the PE teacher is not able to influence all peer relations between students, the means at his/her disposal are enough to reduce unequal treatment of students to a minimum.

Conclusions

The development of intrinsic motivation to participate in physical culture yields firmer intentions to get actively involved in physical education on a regular basis. The present study revealed that such intrinsic motives occurred mainly in students who perceived themselves as competent, i.e. physically and motorically fit. Students with no such perception are less inclined to consider physical education their favorite and most satisfying form of school activity. They may find themselves in a kind of vicious circle: 'Since I don't feel "fit" therefore I don't like PE and therefore I do nothing to feel "fit."' In this context activities undertaken to develop one's perception of being competent and taking active and satisfactory part in PE classes – regardless of the currently possessed level of physical fitness and sport skills, and without the fear of exposure to negative social comparisons – constitute a great challenge. To meet this challenge it is necessary to make absolutely all participants in physical education – regardless of whether they are more or less "fit" – intrinsically moti-

vated to undertake activities in PE classes. If the interpersonal relationships are not based on such values as respect, equality, mutual support and help, the fulfillment of the needs for competence and relatedness will be very difficult.

The discussion of the study results should also concern some research constraints. First of all, the cross-sectional character of the study makes it impossible to make any definitive judgments about causal relationships between the variables examined. As Cwalina mentions, "Positive verification of a model does not prove the existence of causal relationships within it, but only that the model *can* work" [29, p. 17]. It should also be noted that, despite much better goodness to fit indexes in the verified model, they were still "acceptable" to fit rather than "good" to fit. Also the precise definition of the index ranges is conventional and often debatable. Nevertheless, the "acceptable" values of goodness to fit indexes should make us treat the collected empirical data with more caution than the "good" values. We strongly believe that the present study has a significant practical aspect, and the results obtained correspond to those by other authors. The observations and conclusions from the study as well as the theoretical framework presented can be effectively implemented in PE practice.

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Address for correspondence

Krzysztof Sas-Nowosielski
Katedra Humanistycznych Podstaw Kultury Fizycznej
Akademia Wychowania Fizycznego im. Jerzego Kukuczki
ul. Mikołowska 72a
40-065 Katowice, Poland
e-mail: k.sas-nowosielski@awf.katowice.pl

Paper received by the Editors: December 13, 2007.

Paper accepted for publication: August 21, 2008.



STUDENTS' MEMBERSHIP IN SCHOOL SPORTS CLUBS AND THEIR ATTITUDES TOWARDS PHYSICAL EDUCATION AND SPORT IN VARIOUS TYPES OF SCHOOLS

DOI: 10.2478/v10038-008-0020-9

Rajmund Tomik

Chair of Theory and Methodology of Physical Education, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

ABSTRACT

Purpose. The paper discusses the influence of students' membership in school sports clubs (SSCs) on their attitudes towards physical education and sport in various types of schools. The aim of the study was to identify the educational effects of school sports clubs. The variables of attitudes towards physical education and sport were compared between SSC members and non-members in various types of schools. **Basic procedures.** A questionnaire was sent out to 623 randomly selected school sports clubs in Poland. A covering letter explained the purpose and procedure of the test. Correctly filled questionnaires were obtained from 103 school sports clubs. 2704 (1452 from SSC members and 1252 from other students) questionnaires were selected for statistical analysis. The diagnostic questionnaire had been developed by Strzyżewski. **Main findings.** The results obtained show that the respondents' attitude towards physical education and sport is positive but reluctant. Despite the strength of the cognitive component (cognitive scores were the highest ones), the actual participation of respondents in extracurricular sports activities turned out to be insufficient (low values of behavioral scores). **Conclusions.** The analysis of attitudes towards physical education among different school students showed that primary school students scored higher than middle school students, and middle school students scored higher than secondary school students in all attitude indexes except for the cognitive component index. The SSC members display more positive attitudes towards physical education and sport than their non-members in all types of schools.

Key words: educational process, attitudes towards physical education, school sports clubs

Introduction

One of the means of accomplishment of educational aims of physical education could be a school sports club (SSC). Article 7 of the Polish Act on Physical Education and Sport recognizes the legal status of such clubs. A school sports club is regarded as a special kind of sports club, whose members may include pupils, parents and teachers [1]. The functioning of SSCs in Poland is regulated by the Associations Incorporation Act from April 7, 1989, exclusive of regulations concerning the registration procedure, since the school sports clubs are officially registered by the local authorities in Poland [2]. The main objective of school sports clubs is organization of sport in school communities and encouraging all school children to participate in extracurricular sport and physical recreation activities. Parents are often involved in different activities of the SSCs; they provide assistance, pay membership fees and make financial contributions. According to the originators of SSCs in Poland the clubs were to confine their activities to the school or district area only. In reality, however, their

range of activities has become far wider and often crossed the national borders [3].

Access to free sport equipment as well as to substantial subsidies from the "Sport for All Children" program supporting school physical culture associations was – especially between 1994 and 1996 – the main factor behind a dynamic increase in the number of school sports clubs. An important role was also played by local authorities, which provided financial support to the clubs. According to the official data, in 2004 there were 4666 traditional sports clubs. My own data show that there are about 7000 functioning school sport clubs in Poland at present. From the commencement of the "Sport for All" program in 1994 until 2007 10277 SSCs were registered by the Polish Ministry of Sport (formerly the Office of Physical Culture and Tourism, Office of Physical Culture and Sport, Ministry of National Education and Sport). The majority of SSCs are in primary schools (50%), followed by clubs in middle schools and secondary schools [4].

The general program of physical education in Polish schools, which specifies the general objectives of physi-

cal education, emphasizes the necessity of development of the pupil's personality and formulates such educational aims as "Development of the sense of responsibility for one's own and others' health" (primary school) and "Development of the pupil's understanding of the sense of care of his body, fitness and health as a condition for respect towards oneself and others" (middle school) [5]. The aims of physical education, including development of a positive attitude towards physical culture, can be attained both during school PE classes and extracurricular activities, i.e. in school sports clubs. For many years the aims of physical culture at school have included development of instrumental personality dispositions such as acquiring motor skills, development of pupils' physical fitness and acquiring the knowledge about physical culture. These aims also stress the educational influence on the pupil's personality and shaping the "pro-somatic attitudes", which would help the pupils take care of one's physical fitness and health in their adult lives. The "attitude" is defined here as a "relatively stable structure of cognitive and emotional processes and specific patterns of behavior towards a given subject" or a "disposition to generate such processes and behaviors" [6, p. 73]. The structure mentioned consists of three components: cognitive, emotional and behavioral. According to Strzyżewski, in the case of physical culture, the cognitive component comprises knowledge, experience, views and beliefs; the emotional part comprises emotions, sensitivity to stimuli and solid motivation for improving one's health and physical fitness. The behavioral component is one's behavior in everyday life, while taking care of one's own body and physical state [7].

The attitudes of Polish children and adolescents towards physical culture have been researched by a number of authors. The results of these studies were often compared with the results of studies of instrumental aims of physical education, and this way an assessment of the level of preparation to participate in physical culture [8, 9], or the effectiveness of the physical education process was evaluated [10, 11]. Some earlier studies from the turn of the 1980s and 1990s were aimed at standardization of research tools, e.g. Strzyżewski's Questionnaire for Testing Youth's Attitude to Physical Education and Sport [12, 13], and examination of attitudes of selected groups of subjects [14–19]. A different methodology was applied by Wojciechowski [20] in his study of primary school girls, who "adapted Mercer's Attitudes Scale to evaluate the girls' attitudes towards

psychological, social, moral and spiritual values of physical education". The authors of these studies most often assessed their subjects' attitudes as moderately positive but still underdeveloped. Attitudes towards physical education were also researched by authors from other countries, who used the questionnaire survey as their research tool. Koca et al. carried out a study of attitudes in different Turkish schools in terms of school gender composition [21] with regard to sex and sport participation [22]. Sollerhed et al. [23] analyzed correlations between the sense of coherence and positive attitudes to physical education in adolescents. Shropshire et al. [24] used the Pre-Adolescent Attitude to Physical Education Questionnaire in their study to examine school children's general interest in physical education. Stewart et al. [25] compared attitudes towards physical education of primary school and secondary school children. Westerstahl et al. [26] studied the secular trend in sports and physical education attitudes among adolescents.

The aim of the present research was to examine the educational effects of activities of school sports clubs in school communities. Attitudes towards physical culture of SSC-members and non-members were compared on three levels of the Polish education system: primary school, middle school and secondary school. The selected research method was that of a pedagogical experiment, which was to yield subjects' accurate answers to the question about the effects of participation in school sports clubs on students' attitudes towards physical education and sport (for SSC-members and other students). The preliminary tests would have enabled profiling of attitudes towards physical culture in the study groups and the control group. However, considering the scope of research and the long-term membership of subjects in the SSCs the use of such a method seemed impossible. It should be remembered that the attitudes to physical culture are determined by a number of factors, which to a great extent reflect the current status, being a result of many processes.

The following research questions were formulated:

1. What are the attitudes towards physical culture of SSC members as compared with the attitudes of school students who do not participate in SSC activities?
2. What are the differences in the level of attitudes towards physical culture between SSC members and other primary, middle and secondary school students?

The study was a part of a larger research project aimed at the evaluation of significance of SSCs activities

for the development of school sport in Poland. The study was approved by the Bioethics Committee of Research of the Jerzy Kukuczka Academy of Physical Education in Katowice.

Material and methods

Subjects

The questionnaire survey was carried out in November 2005, in 623 randomly selected school sports clubs from all over Poland. The covering letter included the precise description of the questionnaire survey. 103 school sports clubs returned correctly filled questionnaire forms. 2704 forms in total were used for statistical analysis. More than 50% of respondents were primary school pupils (1435), 37% were middle school students (1008) and 10% were secondary school students (261) (Tab. 1). These proportions reflected the number of school sports clubs in particular types of schools in Poland [4]. 1490 (55.1%) girls and 1214 (54.9%) boys took part in the study.

Method

The study used the diagnostic survey method based on Strzyżewski's Questionnaire for Testing Youth's Attitude to Physical Education and Sport. The reliability of the tool had been confirmed by earlier studies on different population samples [8, 12, 13, 18,]. The questionnaire consisted of 67 items; respondents gave their answers to each question on a five-point scale "Definitely,

yes" (4 pts), "Yes" (3 pts), "I don't know" (2 pts), "No" (1 pt) and "Definitely, no" (0 pts). Four attitude indexes were then calculated on the basis of the answers provided: global index (all items), cognitive component index – CCI (26 items), emotional component index – ECI (21 items) and behavioral component index – BCI (20 items). Each index was calculated as the total of points divided into the number of items. With the use of standards developed by Górna, the following index ranges were proposed: 0–0.49 – *definitely negative attitude*, 0.5–1.49 – *negative attitude*, 1.5–2.49 – *neutral attitude*, 2.5–3.49 – *positive attitude*, 3.5–4.0 – *definitely positive attitude* [8].

Statistical analysis

Dependent variables in the study included the four attitude indexes: global, cognitive component, emotional component and behavioral component. The independent variables were SSC membership and school type. First, the Kolmogorov-Smirnov test was used to compare the distribution of the sample with normal distribution, and then separately for the groups of boys and girls from primary, middle and secondary schools, and SSC members and non-members. The distributions of all indexes, with the exception of the global index, revealed statistical differences as compared with normal distribution; however, low skew and kurtosis coefficients and a large sample size made it possible to use analysis of variance (Tab. 2) [27].

The collected sample was processed statistically with the use of parametric tests. In order to examine the

Table 1. The number of subjects with reference to SSC membership, sex and school type

School type (respondents' age)	Number of school students	Number of SSC members	Total	
			<i>n</i>	%
Primary school (11–13 years)	665	770	1435	53.07
Middle school (13–16 years)	460	548	1008	37.28
Secondary school (16–19 years)	127	134	261	9.65
Total	1252	1452	2704	100.00
%	46.30	53.70		100.0

Table 2. Statistical analysis of indexes of attitude towards physical culture – all respondents

Index	<i>n</i>	\bar{x}	Min.–max.	SD	Sk.	Ku.	Max D	Test K-S
Global	2704	2.69	0.67–3.91	0.39	–0.176	0.468	0.025	$p < 0.10$
Cognitive	2704	2.83	1.00–4.00	0.38	–0.046	0.350	0.032	$p < 0.01^*$
Emotional	2704	2.72	0.48–3.90	0.47	–0.396	0.327	0.046	$p < 0.01^*$
Behavioral	2704	2.48	0.45–4.00	0.47	–0.121	0.341	0.037	$p < 0.01^*$

n – number, \bar{x} – mean, SD – standard deviation, Sk. – skewness, Ku. – kurtosis, Max. D – maximum difference

* statistically significant

impact of independent variables (SSC membership, school type) on attitudes towards physical culture, the ANOVA was used to verify whether the independent variables affected the mean dependent variables, i.e. attitude indexes. Also the interactions between individual factors were determined. A significant interaction for two variables meant that the variability of attitude indexes versus SSC membership was different in terms of value and sign (plus or minus) in the school type samples. The analysis of variance was supplemented with a post hoc analysis (Tukey's test) to determine the statistical significance of differences between the values of the dependent variable: particular sample groups.

Results

Global index of attitude

The global index of attitude, reflecting the attitude of all subjects towards physical culture, amounted to 2.69, which indicated a moderately positive attitude. The mean global index of SSC members was 2.82 as compared with 2.55 for the non-members. In all the school types examined the global index was higher among the SSC-members than among other school students. The primary school pupils displayed the most positive attitude towards physical education and sport, followed by the middle school students and secondary school students (Tab. 3).

Table 3. Mean global index values with reference to school type and SSC membership

School type	\bar{x}	<i>n</i>	SD
Primary school	2.72	1435	0.39
Students	2.58	665	0.39
SSC members	2.85	770	0.34
Middle school	2.67	1008	0.39
Students	2.53	460	0.40
SSC members	2.78	548	0.35
Secondary school	2.62	261	0.39
Students	2.48	127	0.38
SSC members	2.76	134	0.35
Total	2.69	2704	0.39

The analysis of variance showed that the school type and SSC membership significantly influenced the level of the global index; however, there was no significant interaction between these two variables. It means that membership in a school sports club had a similar impact on the attitude of respondents from all school types (Tab. 4).

The results of the analysis of particular sample groups differed statistically from one another in the mean values of the global index. In the schools analyzed the SSC membership had a positive influence on the students' attitude towards physical culture – the mean global index was higher in SSC members than in non-members. However, there were no significant differences between the values of the global index in students who did not participate in SSC activities from different

Table 4. Analysis of variance – relationship between the global index and SSC membership and school type

	df effect	MS effect	df error	MS error	F	<i>p</i>
School type	2	1.578	2698.0	0.1351	11.688	< 0.001*
SSC membership	1	29.947	2698.0	0.1351	221.749	< 0.001*
SSC membership – school type	2	0.039	2698.0	0.1351	0.2928	0.746

* statistically significant

Table 5. Post hoc analysis (Tukey's test for different *n*) for the mean values of the global index – comparisons between groups of subjects from different schools

School type	SSC membership		1 (2.58)	2 (2.85)	3 (2.53)	4 (2.78)	5 (2.48)	6 (2.76)
Primary school	no	1		< 0.001*	0.308	< 0.001*	0.265	< 0.001*
	yes	2	< 0.001*		< 0.001*	0.023*	< 0.001*	0.398
Middle school	no	3	0.308	< 0.001*		< 0.001*	0.897	< 0.001*
	yes	4	< 0.001*	0.023*	< 0.001*		< 0.001*	0.999
Secondary school	no	5	0.265	< 0.001*	0.897	< 0.001*		< 0.001*
	yes	6	< 0.001*	0.398	< 0.001*	0.999	< 0.001*	

* statistically significant

schools. The attitudes of SSC members from primary schools were significantly more positive than the attitudes of SSC members from middle schools (Tab. 5).

Attitude component indexes

The highest component index was the cognitive component index (2.83), which indicated a positive attitude; and the lowest was the behavioral component index (2.48), pointing to a neutral attitude. In all other

component indexes the SSC members scored higher than their non-SSC counterparts: cognitive component index – 2.92 for SSC members and 2.74 for other school students; emotional component index – 2.86 and 2.56; and the behavioral component index – 2.65 and 2.29, respectively. In the last index the difference between the two groups of subjects was widest. The value of the cognitive component index was similar in all the school types and always higher among SSC members. The mean values of the emotional component and behavior-

Table 6. Mean values of attitude indexes with reference to school type and SSC membership

School type	<i>n</i>	%	Cognitive component		Emotional component		Behavioral component	
			\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
Primary school	1435	53.07	2.84	0.39	2.76	0.46	2.53	0.46
Students	665		2.73	0.40	2.60	0.48	2.35	0.47
SSC members	770		2.93	0.37	2.90	0.40	2.70	0.39
Middle school	1008	9.65	2.83	0.37	2.68	0.46	2.43	0.49
Students	460		2.74	0.37	2.53	0.49	2.24	0.50
SSC members	548		2.91	0.36	2.81	0.40	2.58	0.42
Secondary school	261	37.28	2.82	0.38	2.61	0.47	2.39	0.46
Students	127		2.73	0.38	2.44	0.47	2.18	0.43
SSC members	134		2.90	0.35	2.78	0.41	2.58	0.41
Total	2704	100.00	2.83	0.38	2.72	0.47	2.48	0.47

Table 7. Analysis of variance – correlations between the attitude indexes, school type and SSC membership

	df effect	MS effect	df error	MS error	F	<i>p</i>
Cognitive component						
School type	2	0.020	2698.0	0.140	0.144	0.866
SSC membership	1	12.570	2698.0	0.140	90.053	< 0.001*
SSC membership – school type	2	0.068	2698.0	0.140	0.486	0.615
Emotional component						
School type	2	3.448	2698.0	0.193	17.844	< 0.001*
SSC membership	1	37.465	2698.0	0.193	193.889	< 0.001*
SSC membership – school type	2	0.083	2698.0	0.193	0.430	0.650
Behavioral component						
School type	2	4.594	2698.0	0.192	23.918	< 0.001*
SSC membership	1	53.240	2698.0	0.192	277.175	< 0.001*
SSC membership – school type	2	0.092	2698.0	0.192	0.479	0.620

* statistically significant

Table 8. Post hoc analysis (Tukey's test for different *n*) for the mean values of the cognitive component index – comparisons between groups of subjects from different schools

School type	SSC membership		1 (2.73)	2 (2.93)	3 (2.74)	4 (2.91)	5 (2.73)	6 (2.90)
Primary school	No	1		< 0.001*	0.997	< 0.001*	1.000	0.004*
	Yes	2	< 0.001*		< 0.001*	0.985	0.001*	0.986
Middle school	No	3	0.997	< 0.001*		< 0.001*	1.000	0.010*
	Yes	4	< 0.001*	0.985	< 0.001*		0.002*	0.999
Secondary school	No	5	1.000	0.001*	1.000	0.002*		0.007*
	Yes	6	0.004*	0.986	0.010*	0.999	0.007*	

* statistically significant

ral component indexes decreased with subjects' age, i.e. they were the highest for the primary school pupils, and were the highest for the SSC members (Tab. 6).

The analysis of variance showed that the school type did not differentiate the cognitive component index, unlike SSC membership. The values of emotional and behavioral indexes revealed that both the school type and participation in SSC activities had a significant impact on emotions and readiness to take part in physical culture. There was no significant interaction between the type of school and SSC membership in any attitude indexes. The differences in the indexes between SSC members and non-members from different types of schools were non-significant (Tab. 7).

The significant differentiation of the cognitive component index values in all types of schools was noted between the SSC members and non-members. The SSC members from all schools featured an almost identical attitude towards physical culture (Tab. 8).

Also significantly higher values of the emotional component index were achieved by SSC members in all school types. Hedonism and motivation to practice sport and physical recreation were the factors which most significantly determined the attitude of primary school pupils, who obtained the highest emotional component index values from all the sample groups (Tab. 9).

The acceptance of pro-somatic patterns of behavior, reflected in the behavioral component index value, was also high among the SSC members from all school types than among the non-members. The primary school pupils taking part in SSC activities achieved the highest index values (Tab. 10).

Discussion

The respondents' answers indicate a generally positive attitude to physical culture, however, not "definitely positive". Their attitude was mostly of cognitive character (the highest cognitive component index values); however, their readiness to take part in extracurricular physical activity was still low (low behavioral component index values). Similar observations were made by authors who used Strzyżewski's questionnaire in their research [8, 11, 14–19]. Taking into account the aims of physical education as well as its health care aspects it seems that the observed tendency in attitude development based on the cognitive rather than behavioral aspects is not entirely positive. The activities of school sports clubs can, however, greatly improve the existing situation. The widest differences in attitude indexes between SSC members and non-members in all types of schools were, in fact, noted in the behavioral component

Table 9. Post hoc analysis (Tukey's test for different *n*) for the mean values of the emotional component index – comparisons between groups of subjects from different schools

School type	SSC membership		1 (2.60)	2 (2.90)	3 (2.53)	4 (2.81)	5 (2.44)	6 (2.78)
Primary school	No	1		< 0.001*	0.113	< 0.001*	0.042*	< 0.001*
	Yes	2	< 0.001*		< 0.001*	0.006	0.017*	0.175
Middle school	No	3	0.113	< 0.001*		< 0.001*	0.612	< 0.001*
	Yes	4	< 0.001*	0.006*	< 0.001*		< 0.001*	0.991
Secondary school	No	5	0.042*	0.017*	0.612	< 0.001*		< 0.001*
	Yes	6	< 0.001*	0.175	< 0.001*	0.991	< 0.001*	

* statistically significant

Table 10. Post hoc analysis (Tukey's test for different *n*) for the mean values of the behavioral component index – comparisons between groups of subjects from different schools

School type	SSC membership		1 (2.35)	2 (2.70)	3 (2.24)	4 (2.58)	5 (2.18)	6 (2.58)
Primary school	No	1		< 0.001*	0.004*	< 0.001*	0.030*	< 0.001*
	Yes	2	< 0.001*		< 0.001*	< 0.001*	< 0.001*	0.262
Middle school	No	3	0.004*	< 0.001*		< 0.001*	0.878	< 0.001*
	Yes	4	< 0.001*	< 0.001*	< 0.001*		< 0.001*	1.000
Secondary school	No	5	0.030*	< 0.001*	0.878	< 0.001*		< 0.001*
	Yes	6	< 0.001*	0.262	< 0.001*	1.000	< 0.001*	

* statistically significant

index. One explanation of this tendency could be the fact that children's and adolescents' systematic participation in physical activities develops their habits of spending their leisure time in an active way, which in turn may reduce the negative effects of a sedentary lifestyle.

In all the indexes, with the exception of the cognitive component index, the primary school pupils achieved significantly higher values than middle school students, whereas the latter scored higher than the secondary school students. Different studies of Polish youth's attitudes towards physical culture with the aid of Strzyżewski's questionnaire have revealed a tendency for all indexes to decrease with the students' age. Primary school students from different communities achieved the mean value of the attitude global index from 2.47 (CCI – 2.83, ECI – 2.69, BCI – 2.36) [14, 19] to 2.66 (CCI – 2.75, ECI – 2.46, BCI – 2.11) [11]; vocational school students – 2.40 (CCI – 2.63, ECI – 2.37, BCI – 2.13) [15]; and secondary vocational school students – 2.34 (CCI – 2.67, ECI – 2.24, BCI – 2.04) [17]. Only high school students examined by Górna and Marszałek obtained similar results to the primary school pupils, i.e. from 2.50 (CCI – 2.80, ECI – 2.50, BCI – 2.24) [8] to 2.60 (CCI – 2.85, ECI – 2.58, BCI – 2.25) [16]. Similar results were achieved by Stewart et al. [25] in their analysis of attitudes towards physical education of U.S. students from junior high and high schools. However, the participation in SSC clubs significantly inhibits the worsening attitude towards physical culture. The post hoc analysis showed that the differences between the mean values of all examined indexes among SSC members from the middle and secondary schools were non-significant. This is mostly due to long-term systematic training in the school sports clubs, which greatly affects the development of students' positive attitudes towards physical culture.

The main research question concerned a comparison of attitudes towards physical education of SSC members and non-members. The analysis of variance showed explicitly that membership in school sports clubs had a significant influence on the level of all attitude indexes in all types of schools. Also Górna in her study of attitudes towards physical culture of secondary school graduates in the Silesian Province, concluded that the adolescents' attitude towards school sport was more positive than to professional sport. She also observed that boys and girls participating in extracurricular sport and recreation activities featured a more positive atti-

tude towards physical culture, better knowledge of physical culture and better motor skills than other students [8, p. 231]. Similar observations were also made by Koca et al. [22] in his analysis of attitudes of 15-year-old training students. Westerstahl et al. [26] in their examination of the secular trend of Swedish teenagers' attitude towards sport and physical education showed that in all the samples studied (groups of boys and girls from 1974 and 1995) students who spent their leisure time actively were more satisfied with their participation in sports events and had no negative emotions about physical education.

What factors shape the more positive attitude towards physical education and sport of members of school sports clubs as compared with other students? Undoubtedly, the decision about enrollment in school sports clubs is an obvious manifestation of one's positive attitude towards physical culture. Sollerhed et al. [23] pointed to a correlation between the feeling of a strong social bond among young people and their positive attitude to physical education and sport. Taking part in sport events, training and competitions has a great impact on the development of strong, positive interpersonal relationships between members of a team and between athletes and coaches. These observations show that, regardless of the school type, the attitude towards physical culture is always more positive in all its components among the SSC members.

In their questionnaire survey of students' attitudes towards PE teachers and organization of PE curriculum Shropshire et al. [24] also noticed other factors affecting one's attitude towards physical education, such as the attitude towards P.E. grades. Undoubtedly, P.E. teachers take into account their students' participation in extra-curricular physical activities in their final marks.

The most interesting conclusion from the present study is a comparison of the structure of attitudes of respondents from three school types. The impact of the dependent variable: school type on the independent variable: cognitive component index failed to produce any significant differences between the respondents. The mean values of the cognitive component index were almost identical among SSC members from the three types of schools (primary school – 2.93, middle school – 2.91, secondary school – 2.90) as well as among non-members (2.73, 2.74, 2.73, respectively). It means that the emotional and behavioral factors are crucial to the worsening of the attitude towards physical culture and sport with age.

Conclusions

The following conclusions can be drawn from the present study:

1. The attitudes of members of school sports clubs to physical education and sport are more positive than the attitudes of non-members', both in the global and component indexes.
2. The attitudes of members of school sports clubs to physical education and sport are more positive than the non-members' attitudes, regardless of the school type.

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Paper received by the Editors: September 18, 2007.

Paper accepted for publication: August 21, 2008.

Address for correspondence

Rajmund Tomik
Katedra Teorii i Metodyki Wychowania Fizycznego
Akademia Wychowania Fizycznego im. Jerzego Kukuczki
ul. Mikołowska 72 a
40-065 Katowice, Poland

e-mail: r.tomik@awf.katowice.pl



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