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LIMITATIONS OF PROLONGED WEIGHT REDUCTION THERAPIES IN OVERWEIGHT AND OBESE PEOPLE: A META-REGRESSION ANALYSIS

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ABSTRACT

Introduction. Presently, obesity is endemic in many countries. Many obese patients also suffer from diseases of high social impact, such as type 2 diabetes and cardiovascular disease. Generally, therapies combining energy-deficient diets and physical activity protocols are used for treating obesity. Nonetheless, presently, no universal intervention with exact parameters exists. The complexity of the problem is further exacerbated by difficulties associated with long-term weight maintenance following weight reduction therapies.

Purpose and objectives of the study. This analysis attempts to assess the impact of duration of combined diet-and-exercise weight reduction protocols on changes in body mass in overweight and obese people. Applied methodology. 3142 publications in total were retrieved by filtering the database of the National Library of Medicine, National Institutes of Health USA by keywords (“weight loss”, “diet” and “exercise”) for the period between 01.01.2008 and 01.01.2018. After a selection procedure was applied, 56 of them were included in this meta-regression analysis and were grouped into three strata according to duration.

Achieved major results. The results showed that therapies of short to moderate duration are the most efficient for weight reduction, with regard to both overall effects and the amount of weight reduced per week. These findings were visualized by graphical representations of the studied data.

Conclusions. On our opinion, short or moderately long weight reduction therapies with scheduled interruptions should be used for treating obesity. This strategy would successfully maintain patients’ psychological wellbeing, as well as prevent relapses and “yo-yo” effects. Originality/Value. Obesity is a problem of complex origins and simple approaches such as calorie counting are rarely effective. This study proposes a “spiral” methodology – short to moderately-long hypo-caloric regimens with scheduled interruptions.

Key words: diet, exercise, obesity, weight reduction, duration

INTRODUCTION

In recent years obesity has reached endemic dimensions, especially in wealthy countries. According to the data from 2015, approximately 39% of the world’s adult population is overweight and obese (Chooi et al., 2019). Among other health hazards, obesity is the main risk factor for diseases of high social impact, such as type 2 diabetes and cardiovascular disease (Cuchiery & Mamo, 2016; Hu et al., 2001; Pisu- unier, 1993). Presently, a lot of research is concentrated on elaborating universally effective methodological principles for manipulating the energy balance of the human body (generally, based on hypocaloric diets and/or physical exercise) for treating obesity. Nevertheless, experts are far from being unanimous about what the exact parameters of a successful therapy for
obesity treatment should be. The complexity of the problem is further exacerbated by difficulties associated with long-term weight maintenance following weight reduction interventions. Frequently, relapses ensue with adverse consequences such as yo-yo effects or recurring progressive unhealthy changes in body composition. In this article, we have attempted to bring clarity on some time-dependent variations in the efficiency of different weight reduction therapies. In our original research, we studied not only changes in body weight but also transformations in body composition, as most health effects of weight reduction are generally mediated by reductions in the absolute and relative amounts of adipose tissue. Accordingly, weight reduction should be achieved (predominantly) at the expense of adipose tissue utilization, with lean body mass being preserved (or, in the best-case scenario, increased). In this article, we published only the results of our research concerning changes in body mass.

The vast majority of existing weight reduction therapies control the energy intake and expenditure. All of them are similar in their attempt (with different rates of efficiency) to negativize energy balance by manipulating habitual energy intakes and/or expenditures via different types of diets and physical activity programs. Irrespective of the immense variety of different existing diets, they can be classified into several large groups, depending on their macronutrient composition. The diversity of physical activity protocols in use is not so great. Generally, low to medium-intensity aerobic exercise of relatively high duration is commonly applied (van Aggel-Leijssen et al., 2001; Brill et al., 2002; Racette et al., 1995; Wilmore et al., 1999). Activities of anaerobic/strength or interval types are rarely used.

Main thesis and hypothesis of the research

In our opinion, short or moderately long weight reduction therapies with scheduled interruptions should be used for treating obesity. This strategy would successfully maintain patients’ psychological wellbeing, as well as prevent relapses and “yo-yo” effects.

METHODOLOGY

Sources of information

This study was based on the data retrieved from the National Library of Medicine; National Institutes of Health USA accessible in https://www.ncbi.nlm.nih.gov/pubmed/. The studies published (randomized clinical trials, crossover trials and cohort studies) between January 15, 2008 and January 15, 2018 were reviewed and filtered by keywords. We used “weight loss”, “diet” and “exercise” as keywords and monitored 3142 publications in total. In addition, search results were filtered by subjects (people) and publication language (English). Fifty-six publications were selected as being eligible for inclusion in the meta-analysis. As some of the trials used more than one experimental group, the total number of data points we analyzed was 85.

Types of weight reduction interventions

We studied combined diet-and-exercise weight reduction therapies irrespective of their particular parameters. Diets studied can be grouped into the following categories:

1. Conventional (hypocaloric) diet (only energy values of foods consumed are manip-
ulated without changing habitual nutrition compositions).
2. High Carbohydrate Diet (only carbohydrate content is controlled for).
3. Low Carbohydrate Diet (only carbohydrate content is controlled for; classic ketogenic diets are included in this category).
4. High Protein Diet (only protein content is controlled for).
5. Low Fat Diet (only the fat content is controlled for; vegetarian and vegan diets are in this category).
6. Intermittent fasting.
7. Diet of very-low-calorie content (very-low-calorie diets or VLCD).
8. Low-glycemic-index diet (only the glycemic index of foods is controlled for; the Mediterranean diet is included in this category).

Physical activity protocols of studied interventions could be classified into the following categories:
1. Aerobic exercise – cyclical activities of different intensities. Some studies used relatively high intensities, which most probably shifted energy supplies partially onto anaerobic pathways.
3. Interval exercise – interval type of training, of both cyclic and resistance types. Some interventions used cyclical exercise with parameters that may be categorized as both interval and high-intensity aerobic. In such cases, we applied the classifications used by the authors.
4. Mixed exercise protocols, which combined aerobic and resistance activities.

Inclusion criteria
We applied the following criteria for inclusion:
2. Published in English or translation of article available.
3. Randomized clinical trials, crossover trials or cohort studies.
4. Number of participants/sample size – minimum 15.
5. Experiment duration – between 4 and 104 weeks.
6. Participants – humans, healthy (excluding type 2 diabetes or metabolic syndrome) overweight or obese people (body mass index, BMI > 25) over 18 years of age.
7. Results reported in absolute values for both mean differences and standard deviations (or variances).
8. Intervention parameters were accurately and precisely defined. For example, a particular type of diet had to be applied instead of mixtures of different diets; exercise parameters should be precisely defined – aerobic, resistance, interval or combinations of these. Protocols, which only generally described the physical activities they used (without disclosing their parameters in detail), were not included.

Exclusion criteria
We applied the following exclusion criteria:
1. Only means and variances (or standard deviations) of baseline and final values of studied parameters were reported. The data of mean differences and their volatilities were not disclosed.
2. Interventions that had studied specific predetermined effects – for example, a 5% reduction in body mass. This type of reporting does not allow for therapy effects to be regressed on their durations. Only experiments that had specified precisely their durations were included.
3. Studies of subjects with different comorbidities (e.g., women with advanced osteoporosis) or having undergone certain medical interventions (such as surgeries
for vertebral disc injury or cancer).

4. Population age could be classified as adolescent, or juvenile (average age < 18 years).

5. Meta-analyses and reviews.

6. Animal studies.

7. Studies not published in English.

Retrieving data
We retrieved mean differences and standard deviations (or variances) for the variables we studied (at levels of significance of at least 95%).

Search in the database
We used the keywords “weight loss”, “diet”, “exercise” separated by the search operator “AND” (standard for www.pubmed.gov). The process of data selection is presented graphically in Figure 1.

Assessing the risk of bias in individual studies
During the selection process, we scrutinized for biases in protocols and reported results in our sample. This type of experiments inevitably carries high potential risk for bias, mainly due to erroneous selection procedures, mistakes in implementation of interventions, and deviations from prescribed protocols (due to an inherent impossibility for controlling exhaus-
tively participants’ behavior into their habitual environments). Notwithstanding that some experiments, in our opinion, lacked power due to small sample sizes or minute mean differences, generally, all included studies were of standard quality regarding the potential risk of inherent biases (whether deliberate or unintentional).

**Summary effect estimation**

We used the “metaphor” package of R for processing our results (Viechtbauer, 2010). For meta-regression, we used the mixed-effects model, which combines both commonly applied linear models. They have different initial assumptions regarding studied data. The fixed-effects model requires studied results to be sufficiently homogeneously distributed. They are treated as a representative sample of the general population of all the studies on the topic. On the other hand, the random-effects model relieves these assumptions by treating data as a random (replaceable) sample of the general population, thereby allowing effects to be assessed, irrespective of heterogeneity. Each model assigns different weights on trials.

The mixed-effects model uses a fixed effect as an intercept (or a base) and random effects as moderator variables (Schwarzer et al., 2015; Basu, 2017). Generally, representative studies (these of large effect sizes, low variances, large sample volumes) receive bigger weights.

**Assessing publication bias**

This procedure assesses the representativeness of a meta-analysis. The main idea is that if some study uses a large sample size and reports expected positive results, it has a much bigger chance of being published than if the outcomes were controversial or statistically insignificant. Publication bias analysis measures the magnitude of this phenomenon. The test is graphical and uses the so-called “Funnel plots” (Schwarzer et al., 2015; Del Re, 2015). Mean effects of studies are presented on the abscissa, and volatilities - on the ordinate (in terms of variances or standard deviations). If no publication bias is found in the data pool, the resultant graph would resemble a funnel with a few points clustered around the summary effect line for large and influential trials that report results of low volatility. Smaller studies of different effect sizes and/or high volatilities would be scattered evenly on both sides of the neutral line. Conversely, if there is publication bias in the sample, it is expected at least one quadrant to be deprived of any points. Conclusions are derived entirely by visual assessment of the data.

**Performing a meta-regression procedure**

We stratified the studied interventions into three subgroups by their duration: short term – between 4 and 12 weeks long; medium term – between 15 and 26 weeks long, and long term – more than 26 weeks long. In the mixed-effects model for meta-regression a fixed-effect is included as base (or intercept), and random effects are represented by additional moderator variables (variables, which are added to the equation for maximizing explained variance). This procedure estimates the influence of each moderator on the summary effect. The coefficients are calculated in two stages. Initially, the software evaluates the amount of residual heterogeneity. Consequently, the model assigns weights on each study and estimates moderator variables (and their confidence intervals assuming a Gaussian distribution). The general form of the mixed-effects model equation is as follows:

\[ y_i = \beta_0 + b_1 x_{i1} + b_2 x_{i2} + \ldots + b_n x_{in} + e_i; \]

where \( x_{ij} \) is the \( j \)-th moderator of the \( i \)-th trial. The terms \( e_i \) represent a process of random noise - \( e_i \sim N(0, \tau^2) \). Similarly, to the simple linear regression model, the term \( \beta_0 \) is the in-
In addition to the conventional model, we fitted our data using the moderator variable with no intercepts. This procedure allows estimating average weekly rate of change of body mass by cohort. For each stratum, this type of modeling assumes that weight change was 0 during the first week and measures its progress for every consecutive week. For example, for long term therapies, the model assumes that during week 27 weight loss was 0 kg and estimates the amount of body mass change for every consecutive week up to week 104. Comparing and analyzing differences in outcomes of the two models for each cohort of publications is an important part of this study.

The procedure also tests for relationships between dependent and independent variables (excluding the base) by calculating the so-called $Q_m$ statistic. Generally, if its value is high, the null hypothesis (lack of relationship) should be rejected. Additionally, a coefficient for residual heterogeneity, $Q_e$, is calculated. If its value is statistically significant, additional moderators should be included in the model to increase the explained between-study variance.

Additionally, two standard procedures were executed for assessing heterogeneity:

1. The so-called $I^2$ parameter was calculated. It measures heterogeneity-induced and randomness-induced fractions of data variance – the fraction of volatility that is explained by the model. High $I^2$ values indicate a highly heterogeneous sample. Although generally, investigators are free to set thresholds of $I^2$, samples of values higher than 30% are interpreted as heterogeneous.

2. The level of (residual) heterogeneity is assessed by the so-called $\tau^2$ statistic. Consequently, it is used for assigning weights to analyzed publications for estimating model coefficients. The higher the value of $\tau^2$, the higher the data heterogeneity. If $\tau^2 = 0$ the points are absolutely homogeneous, and the fixed-effects model should be used.

**RESULTS**

The diagram in Figure 1 presents the process of publication selection of the meta-analysis. Figure 2 is the funnel plot of the complete data set. The distribution of data points is somewhat skewed towards values below the neutral line and there are also several outliers placed outside the funnel. However, around the mean effect size line, the points are more symmetrically distributed, and for that reason, we did not find strong evidence for publication bias in the data pool. For illustration purposes, we also present scatter plots of (un-weighted) effect sizes of studied interventions of different durations for the total sample and by strata (Figure 3).

![Figure 2. Funnel plot of the complete analyzed data set](image)
Figure 3. Scatterplots of changes in body mass vs. therapy duration. 
- a – overall sample; b – short term therapies; c – medium term therapies; d – long term therapies

The complete list of publications that are analyzed in the study is shown in Table 1.

Table 1. Data source of the meta-analysis

<table>
<thead>
<tr>
<th>Data source</th>
</tr>
</thead>
</table>
weight and obese older adults. *Obesity (Silver Spring)*, 22(2), 325–331.


34. Kreider RB, Serra M, Beavers KM, Moreillon


44. Straight CR, Berg AC, Reed RA, Johnson MA, Evans EM. (2018). Reduced body weight or increased muscle quality: Which is more important for improving physical function following exercise and weight loss in overweight and obese older women? *Exp Gerontol.*, 108, 159-165


**Therapies of short duration**

The results about the data fitted by the two models are shown below. Thirty-five data points were included in this stratum in total. For the model without an intercept, the $Q_e$ coefficient is statistically significant – a sign that only a small fraction of between-study heterogeneity is explained (Table 2). Expectedly, more moderators are necessary for this data pool. The calculated moderator variable (“duration”) is highly statistically significant and lies in a tight confidence interval. On the other hand, the heterogeneity of the data is quite high $I^2 = 94.39\%$ (the unexplained heterogeneity) and $\tau^2 = 17.0535$ (the residual heterogeneity), although the standard error of $\tau^2$ is relatively high – 4.865.

$$\tau^2 = 17.0535 \ (SE = 4.8650); \ I^2 = 94.39\%; \ Q_e \ (df = 34) = 194.6406, \ p < .0001$$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>-0.5124</td>
<td>0.0675</td>
<td>-7.5955</td>
<td>&lt; .0001</td>
<td>-0.6447</td>
<td>-0.3802</td>
</tr>
</tbody>
</table>

*Table 2. Results of the model without an intercept (therapies of short duration)*
On the other hand, when an intercept is included, heterogeneity expectedly decreases at the cost statistical significance being lost by the estimates (Table 3). The intercept value should be equal to body mass change during week 0, which is obviously meaningless. As the lowest duration in the sample was 4 weeks, the summary effect can be calculated as intercept + 4*(duration) and equals -5.5839. Irrespective of the fact that the p-value of the base is close to 0.05, this result is not statistically significant by the standards and should be considered as only indicative.

$$\tau^2 = 15.8377 \text{ (SE = 4.6304)}; \ F = 88.64\%; \ Qe \ (df = 33) = 178.6734, p < .0001;$$

$$Qm \ (df = 1) = .0216, p = .8832$$

Table 3. Results of the model with an intercept (therapies of short duration)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-5.4163</td>
<td>3.2049</td>
<td>-1.6900</td>
<td>.0910</td>
<td>-11.6978</td>
<td>0.8651</td>
</tr>
<tr>
<td>Duration</td>
<td>-0.0419</td>
<td>0.2849</td>
<td>-0.1469</td>
<td>.8832</td>
<td>-0.6002</td>
<td>0.5164</td>
</tr>
</tbody>
</table>

**Therapies of medium duration**

Thirty-five trials were included in this stratum. Below are shown the results of modelling without and with an intercept (Table 4 and 5).

Model 1:

$$\tau^2 = 14.3015 \text{ (SE = 4.3579)}; \ F = 87.77\%; \ Qe \ (df = 34) = 279.4173, p < .0001$$

Table 4. Results of the model without an intercept (therapies of medium duration)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>-0.3722</td>
<td>0.0314</td>
<td>-11.8556</td>
<td>&lt;.0001</td>
<td>-0.4338</td>
<td>-0.3107</td>
</tr>
</tbody>
</table>

Model 2:

$$\tau^2 = 11.1012 \text{ (SE = 3.7093)}; \ F = 83.70\%; \ Qe \ (df = 33) = 279.3636, p < 0.0001;$$

$$Qm \ (df = 1) = 0.4426, p = .5059$$

Table 5. Results of the model with an intercept (therapies of medium duration)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-5.4163</td>
<td>3.2049</td>
<td>-1.6900</td>
<td>.0910</td>
<td>-11.6978</td>
<td>0.8651</td>
</tr>
<tr>
<td>Duration</td>
<td>-0.0419</td>
<td>0.2849</td>
<td>-0.1469</td>
<td>.8832</td>
<td>-0.6002</td>
<td>0.5164</td>
</tr>
</tbody>
</table>

**Therapies of long duration**

The number of experiments in this stratum is smaller – 15. The no-intercept model measured high heterogeneity in this stratum $F = 87.09\%$ and $\tau^2 = 15.3921$ – Table 6 (but the standard error of $\tau^2$ is also extremely high – 7.21 or almost 50%). The duration variable is of high statistical significance. $Qe$ statistic is statistically significant – $p < .0001$:

$$\tau^2 = 15.3921 \text{ (SE = 7.2100)}; \ F = 87.09\%; \ Qe \ (df = 14) = 123.7249, p < .0001$$
Table 6. Results of the model without an intercept (therapies of long duration)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>-0.1108</td>
<td>0.0183</td>
<td>-6.0511</td>
<td>&lt; .0001</td>
<td>-0.1467</td>
<td>-0.0749</td>
</tr>
</tbody>
</table>

The second model reached statistical significance for the base but lost it for the duration (Table 7). Expectedly, heterogeneity decreases, in this case, dramatically:

$$\tau^2 = 4.7571 \ (SE = 3.0982); \ F = 66.62\%; \ Qe \ (df = 13) = 46.7756, \ p < .0001$$

$$Qm \ (df = 1) = .6216, \ p = .4305$$

Table 7. Results of the model with an intercept (therapies of long duration)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>p</th>
<th>CI l.b.</th>
<th>CI u.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-8.9287</td>
<td>1.8885</td>
<td>-4.7280</td>
<td>&lt; .0001</td>
<td>-12.6301</td>
<td>-5.2273</td>
</tr>
<tr>
<td>Duration</td>
<td>0.0235</td>
<td>0.0298</td>
<td>.7884</td>
<td>.4305</td>
<td>-0.0349</td>
<td>0.0819</td>
</tr>
</tbody>
</table>

The plots in Figure 3 show highly noisy pictures of visible heteroscedasticities and no distinguishable regression trends. In the first two diagrams, effect sizes are grouped in several layers by duration. If a clear positive relationship between weeks spent on therapy and the amount of weight loss existed, then a negatively sloped regression line should be noticeable, which in our graphs was not the case. Furthermore, no visible differences exist in ranges of effect sizes for all the duration layers. Roughly speaking, this finding indicates a lack of clearly noticeable relation between weight loss and therapy duration within strata (although the same is true for the overall sample – see the first plot). Technically, a simple linear regression model would find some negative regressions for both short and moderately long therapies. For short-term interventions, effect sizes increase to some extent in sync with duration. The trend is somewhat blurred, but still visible for moderately long therapies. On the other hand, the plot of long-term interventions even shows a slightly positively sloped (imaginary) regression line with effect size inversely proportional to duration. Interestingly, for long term interventions, the data points in the middle of the graph (which correspond to 52-54-week long interventions) are almost uniformly distributed along the whole range of measured effect sizes. Nonetheless, if assessed in a strictly statistical sense, this sample would deliver a mean value (which would be smaller than that of the moderately long therapies) and a standard deviation. However, in light of all abovementioned considerations, these numbers would beget misleading conclusions. Additionally, only a few data points are included for durations different than this one, which complicates the statistical interpretation. Nevertheless, the longest interventions are clearly far from being the most effective within the sample. It should be noted, however, that if weighted effect sizes (which the mixed-effects model calculates) were plotted these graphs would be somewhat different. Nevertheless, the big picture would not change much.

The analysis of the results raises some interesting considerations. All the three strata of analyzed studies are highly heterogenic. An interesting trend emerges in the estimated summary effects between groups – the intercepts in the mixed-effects models (for short term interventions the “duration” variable should be
multiplied by 4 and added to the intercept as the shortest therapies included in the sample are 4 weeks long). Generally, common wisdom dictates that the amount of body weight lost to therapy should increase (although, not necessarily linearly) with its duration. This line of thinking implies that the longest interventions should deliver the biggest effects. Our results, however, draw a different picture – one of an inverted parabolic relationship with a maximum summary effect of -11.1 kg for moderately long interventions and -5.58 kg and -8.93 kg for short- and long-term therapies, respectively. Accordingly, this finding should classify these therapies as the most effective ones for weight reduction. On the other hand, this conclusion may be premature and over-simplistic as we have stratified our overall sample somewhat arbitrarily. If we delve into the calculations of the non-intercept mixed-effects model for the three groups of studies, a more detailed picture becomes visible. Estimates of moderator variables (the “duration” variable in no-intercept meta-regression results) clearly depict a decelerating pace of weight reduction by strata – from -0.5124 kg per week for short term interventions to -0.3722 kg per week for moderately long ones to -0.1108 kg per week for long term therapies (all estimates are highly statistically significant). The same trend emerges in the mixed-effects model with an intercept: while for short term therapies the moderator is negative (although, insignificant statistically), for the medium term and long term interventions it is positive, which means that summary effects decrease with time. (Short term interventions are somewhat expected to show the highest results as it is well established that at the initial stages of a diet plan, much water is lost with body mass). Theoretically, we could extrapolate these findings to the general population of trials of weight reduction (of which our group of studies is considered to be a random sample by the model), but the inverted U-curve of summary effects by strata infers somewhat conflicting conclusions: weight regains should be present at some points in time in long term interventions, in order to explain these findings. In our opinion, most probably, they are due to relapses caused by the psychological discomfort of long-lasting dieting. On the other hand, the number of trials in the long-duration group is only 15, which necessitates a cautious interpretation. Additionally, the model calculated high values of heterogeneity statistics and statistically significant Qe coefficients for all studied groups. This means that we are analyzing a highly scattered sample in which the “duration” moderator variable explains only a tiny bit of the sample variability. Generally, these results statistically proved that long-term interventions are less effective for weight reduction than those of short to moderate durations, which corroborates some previous findings (Ashtary-Larky et al., 2017, Nackers et al., 2010; Byrne et al., 2018). Interventions that are based on changing habitual nutrition behaviours for long periods of time are difficult to adhere to. These conclusions are in agreement with the results of the 2 experiments with the longest durations. Tay J et al. studied the effect of a combined 2-years long diet-and-exercise intervention on overweight and obese people with type 2 diabetes and reported moderate weight loss (Tay et al., 2017). Although the experiment was claimed to be successful, almost half of the participants did not manage to complete it. In our opinion, if their hypothetical results had been included, the outcomes would have been even more moderate. In the other trial, Beavers K et al. studied how an 18-month long diet-and-exercise intervention affected obese older adults (Beavers et al., 2014). They reported a relatively high adherence rate of 86.5% and moderate reductions in body mass. Their protocol, however, includ-
ed periods of maintenance, which, in our opinion, greatly facilitates adherence and alleviates potential diet-induced psychological discomforts. Frequently, long term therapies are associated with occasional relapses, during which patients regain some or all of the weight they have lost (Gibson & Sainsbury, 2017; Sacks et al., 2009). These interruptions diminish the efficiency of interventions in terms of both the net amount of lost weight (a pattern clearly visible in our sample of long-term therapies) and the rate of weight loss per unit of time. For that reason, in agreement with some experts, we recommend long term weight-reduction plans to contain scheduled regular interruptions (Brehm, 2014). Such an approach is also commonly used by many bodybuilders during their pre-contest preparation routines.

CONCLUSION

In conclusion, our meta-regression analysis proved that the highest rate of weight reduction is reached for moderately long therapies and slows down or vanishes for long-term interventions, mainly (in our opinion) due to declining with time adherence rate (Greenberg et al., 2009, Gillis-Januszewskia et al., 2018). Additionally, short-term interventions induce the fastest weight loss per unit of time. Mathematically, these numbers prove that relapses should occur during long term interventions, which reduces or nullifies any achieved weight loss. Accordingly, most probably, body mass reduction therapies should be maintained short to moderately long and should be cycled several times in order to achieve expected results without provoking relapses, frustrations or burnouts. In our opinion, this approach is vital for the psychological comfort of overweight and obese patients. Their weight reduction goals require a lot of time to be achieved as they carry big amounts of excessive body weight. With increased food abstention time, the risk of relapses, and consequently entering yo-yo effect spirals due to psychological reasons, increases. Bitter experiences from failed weight reduction attempts (which are quite common in this cohort) only further aggravate the problem. Applying short to moderately long interventions separated by occasional interruptions could be an efficient method for maintaining weight loss in the long term, while concomitantly sustaining patients’ self-esteem and well-being high due to the sustainable and permanent “step-by-step” successful process of losing kilograms in such a fashion that they can achieve/witness it.

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DYNAMICS OF DEVELOPMENT AND EVALUATION OF AGILITY IN SCHOOL EDUCATION (1st-12th GRADE)

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ABSTRACT
Physical activity is an important criterion for a healthy lifestyle and a prerequisite for improving the motor abilities of adolescents.

The aim of this study is to establish the level of development of physical quality agility in all stages of school education. In order to fulfill the set aim of the research, we used sports-pedagogical testing. The research was carried out with 232 pupils from 1st to 12th grade. We used variation analysis and comparative analysis with t-criterion of Student for independent samples to process the study results. Following the dynamics of the development of the studied indicator between the different classes, we report a positive increase six times, and a decrease in the result - three times (from 2nd to 3rd grade; from 7th to 8th grade and from 10th to 11th grade). Between grades 5th – 6th and 8th – 9th there was no increase in the results. The average number of points reported for each class ranged between 9 and 13 points, which according to the evaluation table means a “GOOD” assessment of agility development. Our study shows that the dynamics of the mean level of the researched indicator in the age aspect changes regressively, with the values decreasing from 1st to 12th grade. Comparing the changes in the mean values of pupils divided by class and gender, we established that, overall, boys are faster than girls when performing the test.

Key words: agility, pupils, testing, quality evaluation

INTRODUCTION
The educational process of physical education is aimed at mastering the knowledge, skills and habits, developing the motor, moral, and volitional qualities of the adolescents. In turn, physical fitness in the training process aims at a versatile physical development, enhancing the functionality of all organs and systems in the human body, strengthening and stiffening of the child’s organism from the beginning of school age (Borukova, 2019).

Pupils’ insufficient motor activity in the modern technological world leads to disruptions in the functioning of the various systems of the child’s organism, reduces the ability to work, and impairs health. Promotion of physical activity and physical fitness among children is an important public health goal for governments, health authorities and other local public health stakeholders (Jarani et al. 2015). The school environment plays a crucial role in providing opportunities for children to engage in physical activity (Gallotta et al., 2009) and it serves as an ideal setting for school-based physical activity intervention (Kriemler et al., 2011). According to Lee, Burgeson, Fulton, Spain, (2007), Sallis, (2004), physical education must be consid-
ered as a powerful and valuable setting for structured interventions affecting health outcomes, including physical fitness and physical activity among children.

In the theory of physical education, the different sides of motor abilities are defined as motor qualities – speed, strength, endurance, flexibility, and agility (Rachev et al., 1998; Jeliazkov, Dasheva, 2017).

Agility is a complex motor quality and reflects the body’s ability to cohere (coordinate) individual movements and actions across time, space and effort, adequate to the motor task (Zhelyazkov, Dasheva, 2017; Hadzhiev et al., 2011). Metikos et al., (2003) are of the opinion that it is the human ability to displace the body in space quickly and efficiently under the conditions of repeated performance of sudden stops and changes of direction, but Young and Farrow (2006) defined it as a rapid whole body movement with change of velocity or direction in response to a stimulus. According to Gabbett et al. (2008) and Sheppard et al. (2006) the cognitive component of agility is very important. However, the mechanics associated with agility are also essential for skill execution. Change-of-direction speed helps describe these mechanics, in that it incorporates the ability to accelerate and decelerate rapidly, in addition to changing direction (Young, Farrow, 2006).

The level of development of agility is determined by a number of factors (Kleshchev, 1997). Of great importance are the highly developed muscle sensation and the flexibility of the nervous processes. The degree of their manifestation depends on the speed of formation of coordination bonds and the speed of transition from one condition and reaction to another. According to the author, the basis of agility is coordination abilities, which mean the ability to quickly, accurately, appropriately and effectively solve motor tasks (Bakulev, 2006; Lyah, 2010; Kleshtev, 1997).

According to Lyah (1983) and Hadzhiev (2009) motor coordination is to some extent genetically determined. Dimitrova (2014) points out that the coordination of movements has a heredity coefficient of Holzinger 45%, which means that the possibility of manifestation of phenotypic factors is significant.

It has been established that in different age periods, the development of coordination abilities takes place in different directions and at different times. For example, at the age of 7-8 years motor coordination is characterized by instability of speed parameters and rhythm. In the period from 11 to 13-14 years the accuracy of differentiation of muscular efforts is increased and the ability to reproduce the set tempo of movements is improved. The 13-14-year-old boys have a high ability to master complex motor coordination. At the age of 14-15 there is a slight decrease in spatial analysis and coordination of movements. In the period 16-17 years, the improvement of motor coordination to the level of adults continues, and the differentiation of muscular efforts reaches an optimal level (Chaikin, 2013; Holodov, Kuznetsov, 2000).

The movements that are used within particular change-of-direction speed tests are wide and various. As a result, numerous tests have been developed to assess change-of-direction speed in athletes (Lockie et al. 2013). Some examples include: 5-0-5 for rugby league (Gabbett et al., 2008) and soccer (Maio Alves et al., 2010) players; Illinois agility run for rugby union (Jarvis et al., 2009) and soccer (Vescovi et al., 2006) players; T-test for soccer players (Sporis et al., 2010); pro-agility shuttle for American football (Sierer et al., 2008) and soccer (Vescovi et al., 2006) players; and 3- cone drill for American foot-
ball (Sierer et al., 2008) and rugby league (Gabbett et al., 2008) players. While the value of these tests is widely acknowledged, there are some limitations and they may not be relevant to the complex change-of-direction movement demands of many sports (Gabbett, Benton, 2009). There are also few change-of-direction speeds tests that assess the ability to sharply change direction of movement. This is pertinent, as the space used for movements within a change-of-direction speed assessment are important considerations for correctly administering a test (Metikos et al., 2003).

In the field of physical education, there are various tests to assess the agility and coordination abilities of pupils. The most commonly used are: throwing a ball at a target, running on a low gymnastic bench (Grozdeva, 2010), orientation shuttle run test for speed, hanging target throw to assess upper limb response orientation ability, low jump to assess kinesthetic differentiation ability, backwards ball throw at a target (Gallotta, 2010, Jaranı et al. 2015, Tankoucheva, 2019), T-test for agility (Borukova, 2019, Miladinov et al., 2019).

Some authors (Zamashkin, Tolstova, 2013, Pisarenkova, 2010,) are of the opinion that the improvement of coordination abilities and other physical qualities at school age is an urgent task of the school process. In addition, the primary school age is the most favorable in this respect.

Therefore, it was of interest to us to trace the development of agility during the age periods of the school education, as well as the influence of physical education classes in Bulgarian schools.

The aim of our study is to establish the level of development of physical quality agility in all stages of school education. In order to achieve the aim, we set the following tasks:

✓ To conduct a testing of the pupils from 1st to 12th grade.
✓ To process and analyze the obtained results.
✓ To make a qualitative evaluation of the level of development of the agility quality of the studied pupils.

METHODOLOGY

The research was aimed at exploring the main indicators of physical fitness of pupils from 1st to 12th grade. To realize it, we used a test battery which bears information about the main indicators of physical ability. The battery includes five tests – running 30 m, standing long jump, medicine ball throwing (1 kg), running 200 m (shuttle running), T-test for agility and spatial coordination (Miladinov, et al., 2019).

The first four tests are standard and are applied in physical education and sport classes. The only new test is that for agility and spatial coordination. Therefore, in this article we will present and analyze precisely the data from the study of all pupils for this test only, and the results of the other tests and the relationship between them will be subject of another publication.

T-test description: Four small rubber hoops (15-20 cm in diameter) are placed in the shape of the letter T (Figure 1). There is one tennis ball in each hoop. Performance: The pupil stands behind the hoop at the start/finish position in a standing position. At the starting signal, the pupil bends down, takes the ball and moves to the rest of the hoops in the direction indicated with figures from 1 to 6 (see Figure 1). Pupils take the ball from every following hoop, leaving the one they have taken from the previous hoop. The recording ends as soon as the ball touches the start/finish area of the hoop. Measured with accuracy of up to 0.01 sec. The student is entitled to only one attempt.
Limitations of the research

The research was carried out within the framework of a national scientific project of National Sports Academy “V. Levski” and the Ministry of Education and Science for the study of the physical capacity of pupils from secondary schools in the Republic of Bulgaria. In this study, we only present data that was personally obtained from the researchers—authors of this article. The device used to detect the time to perform the test is a handheld chronometer. Unfortunately, in Bulgarian schools there is no possibility to use modern electronic equipment for measuring time, which at this stage does not allow us to make our study more in-depth.

Research methods and indexes

In order to fulfill the set tasks and aim of the research, we used the following methods: study of the specialized literature and sports-pedagogical testing.

Procedure

The research was carried out in October 2018 at Secondary School “Chernorizets Hrabar” in the town of Plovdiv. The sport-pedagogical tests were applied at school within the regular physical education and sports classes. We studied 232 pupils, including 123 boys and 109 girls. The pupils participated voluntarily in the research. We studied one class of students from 1-st to 12-th grades, ages 7 to 18. Before the test, detailed instructions and demonstration were provided. To perform the test, we used the necessary equipment: a stopwatch, 4 small rubber hoops, 4 tennis balls. Each participant performed the test with only one attempt.

Data analysis

The results from the research were processed with math-statistical methods: variation analysis and comparative analysis with t-criterion of Student for independent samples (Gigova, 2002). All analyses were processed and illustrated with the SPSS statistical package, version 19.0 and Excel 2013.

RESULTS AND ANALYSIS

The coefficient of variation in almost all grades from the primary and pre-high school stages of the major educational degree showed the approximate uniformity of the values in the groups. It ranged from 12.2 to 17.4%. Only the 5th grade showed homogeneity of values, with a coefficient of variation of 9.6% (Table 1).
Table 1. Variation analysis of the indicator “T-test of agility” in primary and pre-high school stages of the major educational degree (1st-7th grade)

<table>
<thead>
<tr>
<th>Grade</th>
<th>n</th>
<th>Mean</th>
<th>min</th>
<th>max</th>
<th>R</th>
<th>S</th>
<th>V%</th>
<th>As</th>
<th>Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-st</td>
<td>18</td>
<td>20.63</td>
<td>17.96</td>
<td>27.63</td>
<td>9.67</td>
<td>2.78</td>
<td>13.51</td>
<td>2.03</td>
<td>1.69</td>
</tr>
<tr>
<td>2-nd</td>
<td>20</td>
<td>19.38</td>
<td>15.89</td>
<td>29.93</td>
<td>14.04</td>
<td>3.32</td>
<td>17.13</td>
<td>4.80</td>
<td>2.01</td>
</tr>
<tr>
<td>3-rd</td>
<td>20</td>
<td>20.00</td>
<td>16.15</td>
<td>27.15</td>
<td>11.00</td>
<td>3.17</td>
<td>15.88</td>
<td>-0.29</td>
<td>0.77</td>
</tr>
<tr>
<td>4-th</td>
<td>25</td>
<td>18.28</td>
<td>14.74</td>
<td>22.06</td>
<td>7.32</td>
<td>2.23</td>
<td>12.20</td>
<td>-1.31</td>
<td>0.29</td>
</tr>
<tr>
<td>5-th</td>
<td>19</td>
<td>17.43</td>
<td>14.37</td>
<td>20.12</td>
<td>5.75</td>
<td>1.68</td>
<td>9.64</td>
<td>-1.19</td>
<td>-0.08</td>
</tr>
<tr>
<td>6-th</td>
<td>22</td>
<td>17.43</td>
<td>13.08</td>
<td>21.78</td>
<td>8.70</td>
<td>2.24</td>
<td>12.89</td>
<td>-0.57</td>
<td>0.17</td>
</tr>
<tr>
<td>7-th</td>
<td>17</td>
<td>16.04</td>
<td>13.86</td>
<td>24.59</td>
<td>10.73</td>
<td>2.78</td>
<td>17.38</td>
<td>4.83</td>
<td>2.03</td>
</tr>
</tbody>
</table>

Overall, there were large differences between the minimum and maximum values in the different classes, but a more significant impression was the big difference for pupils in the 2nd and 3rd grades of 14.04 and 11.00 seconds. The best result was reported for the 6th grade pupil (13.08 sec) and the lowest for the 2nd grade pupil (29.93 sec). In tracking the dynamics of the averages for the age-appropriate agility test for pupils from the primary and pre-high school stages of the major educational degree, there was an improvement in the results from 1st to 7th grade – from 20.63 sec. up to 16.04 seconds. In our opinion, this is logical, due to the natural age of the children and the development of their spatial orientation and coordination. Exceptions are the pupils from the 3rd grade, where the results were worse.

The data for all grades in the high school stages of the secondary educational degree showed approximate homogeneity of the groups with a coefficient of variation above 12% (V is 12.8 to 16%). The difference between the best and worst scores in the different classes ranged from 7.80 to 9.42 seconds, with a 10th grade pupil completing the test in the shortest time (12.92 seconds), and the 11th grade the slowest - 22.88 sec. (Table 2).

Table 2. Variation analysis of the “T-test of agility” in high school stage of the secondary educational degree (8th-12th grade)

<table>
<thead>
<tr>
<th>Grade</th>
<th>n</th>
<th>Mean</th>
<th>min</th>
<th>max</th>
<th>R</th>
<th>S</th>
<th>V%</th>
<th>As</th>
<th>Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-th</td>
<td>23</td>
<td>17.37</td>
<td>14.06</td>
<td>21.86</td>
<td>7.80</td>
<td>2.23</td>
<td>12.83</td>
<td>-0.16</td>
<td>0.72</td>
</tr>
<tr>
<td>9-th</td>
<td>24</td>
<td>17.34</td>
<td>13.92</td>
<td>22.21</td>
<td>8.29</td>
<td>2.33</td>
<td>13.46</td>
<td>-0.54</td>
<td>0.36</td>
</tr>
<tr>
<td>10-th</td>
<td>23</td>
<td>16.23</td>
<td>12.92</td>
<td>22.03</td>
<td>9.11</td>
<td>2.15</td>
<td>13.25</td>
<td>2.45</td>
<td>1.39</td>
</tr>
<tr>
<td>11-th</td>
<td>12</td>
<td>16.75</td>
<td>13.46</td>
<td>22.88</td>
<td>9.42</td>
<td>2.48</td>
<td>14.80</td>
<td>2.61</td>
<td>1.29</td>
</tr>
<tr>
<td>12-th</td>
<td>9</td>
<td>16.00</td>
<td>13.40</td>
<td>21.60</td>
<td>8.20</td>
<td>2.56</td>
<td>16.01</td>
<td>2.23</td>
<td>1.39</td>
</tr>
</tbody>
</table>

The analysis of the mean values reported for the 8th to 12th grade pupils again showed a slight improvement in the results. In the high school stages of the secondary educational degree, the values were quite close between the different classes (from 17.37 to 16.00 sec).

When we compared the average values of the classes of the two grades of school education, we noticed a certain retention in the result with similar values from the 1st to the 3rd grade, and then, at the end of the primary education, in 4th grade, the score improved (from 20.63 to 18.28 sec.). This tendency was again evident in the 5th and 6th grades (retention) and improvement at the end of the 7th grade pre-high school stage (Figure 2).
In the first two years in high school stage of the secondary educational degree (8th and 9th grade) pupils showed the same results as those in 5th and 6th grades (17.43 sec) and much lower than in 7th grade (16.04 sec). This, in our view, is not a good sign of the level of agility development and more work is needed to develop and improve this quality. The results we reported at the end of secondary education (10th–12th grade) were also close in value. Compared to the previous classes, their results were improving.

Figure 2. Dynamics of mean values for pupils from 1st to 12th grade

Figure 3 shows the differences between the mean values of the “T-test of agility” in boys and girls of all the classes studied. It can be seen that in most classes, girls had higher values than boys, which for a particular test, however, means lower performance. From our personal observations during pupils testing, we can state that there are three main reasons for this:

- slow movement between stations (slower velocity ability – speed),
- inaccurate placement of the balls in the hoops (subject agility),
- faults in the sequence of placing the balls in the hoops (weak spatial orientation).

The exceptions are grades 3rd and 6th, where girls’ scores were better than boys’ scores.

Figure 3. Dynamics of average values for boys and girls from 1st to 12th grade

Average values of indicator “T-test of agility” for boys and girls

The results obtained are related to the fact that in all periods of school age girls and boys have individual characteristics in the level of development of agility. Its various manifestations have a certain age-dynamics related to the biological development of children, as the highest levels of their natural growth are in pre-puberty. For example, gender differences in the ability to spatial orientation are relatively low in the age group of 7 to 11 years. This is observed in favor of boys aged 12 years (Hirtz, Starosta, 2002). The highest growth rates of the motor response are achieved between the ages of 7 and 10 years. At the age of 13, gender-specific differences were found in favor of boys (R. Hirtz, 1985).

Following the dynamics of the development of the studied indicator between the different classes, we report a positive increase six times, and a decrease in the result was three (from 2nd to 3rd grade; from 7th to 8th grade and from 10th to 11th grade). Between grades 5th–6th and 8th–9th there was no increase in the results (Figure 4).

A deeper insight into the values of the t-criterion of Student shows that for almost all indicators temp is less than t critical (tcritical = 2.05) (Figure 4). This gives the reason for the high guarantee probability (Pt ≥ 95%) that the null hypothesis is confirmed, according to which the observed improvement in the results is not significant and can be explained by random reasons (positive growth, but insignificant between grades 1st/2nd; 4th/5th; 6th/7th; 9th/10th and 11th/12th grade).
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A deeper insight into the values of the t-criterion of Student shows that for almost all indicators $t_{emp}$ is less than $t_{critical}$ ($t_{critical} = 2.05$) (Figure 4). This gives the reason for the high guarantee probability ($P_t \geq 95\%$) that the null hypothesis is confirmed, according to which the observed improvement in the results is not significant and can be explained by random reasons (positive growth, but insignificant between grades 1st/2nd, 4th/5th, 6th/7th, 9th/10th and 11th/12th grade).

**Figure 4. Increase and significance of differences between average levels of studied indicator for pupils from 1st to 12th grade**

We can also see in the figure that the t-criterion of Student had a value of 2.05 only for the increase between the 3rd and 4th grade. This gives reason, in terms of the level of agility development, to reject the null hypothesis and to consider the alternative, according to which the improvement in the result between these classes is statistically significant.

Evaluation of the level of physical quality agility of pupils from school education we prepared according to the developed national system for assessing the physical capacity of pupils from 1st to 12th grade in the Republic of Bulgaria. In it, the test results tables are divided by age and gender, and a 20-point scale is used to evaluate these results. The following guidelines were followed in the evaluation:

- First step – is to determine the number of points for the test result, depending on the gender and age of the pupils.
Second step – is to equate the number of points obtained with the six-point rating system (Miladinov et al., 2019).

Figure 5 presents the mean evaluation of the results of the study in boys and girls. Almost all pupils’ results fell into the grading scale from 8 to 14 points. They received evaluation of “Good 4”. Only the score of the boys from the 3rd grade was lower – “Satisfactory” (7.4 points).

**DISCUSSION**

The results of the study show a tendency to improve agility at different ages. It is most noticeable in pupils from primary and pre-high school stages of the major educational degree (from 7 to 13 years), which we believe is natural, on the one hand, the natural development of children, and on the other – it is related to the sensitive periods of development. For coordination abilities as a component of agility, these periods are between 7 and 12 years (Dimitrova, 2014) and after puberty, but the highest indices appear at the age of 13-14 years (Borukova, 2019). A statistically significant difference, however, is observed only between 3rd and 4th grade pupils. This is probably related to the development of the motor analyzer at this age - 10-11 years. It has been found that each age group has sensitivity to the acquisition of specific motor skills (Weineck, 2001).

The comparative analysis shows poorer results for pupils in the first two years of high school stage of the secondary educational degree (8th and 9th grade). This shows a low level of development of agility and spatial coordination in this age group. In the following age periods (10th – 12th grade) there is again a tendency to improve the results, which, however, is not statistically significant. This may be due to the following facts: insufficient sports facilities; conducting the physical education classes by class supervisors and the lack of specialists for extra hours. They can affect negatively the degree of mastery of the necessary motor skills and habits as well as the development and manifestation of basic physical qualities, including agility (Tankousheva, 2019).

There is no difference in the evaluations obtained (based on the results achieved) between the separate classes. This shows an insufficiently good level of agility development at different ages. Therefore, more attention...
should be paid on strategies focusing on the quantity and quality of physical education classes (Sallis et al., 2012; Veugelers, Fitzgerald, 2005; Wang, Pereira, Mota, 2005). Physical education should provide encouragement to increase physical activity and promote activity and exercises that aim to improve a broad range of physical fitness parameters including both health (e.g. cardiovascular fitness, flexibility and body composition) and skill-related (e.g. agility, balance, power, speed and coordination) physical fitness (Jarani et al., 2015).

Considering that children are in the maturation process, affecting their capability to learn particular motor skills, as well as the increasing movement’s complexity, it is essential to develop coordination during early school age. An effective training program for children must take into account the psycho-physical particularities of each age range, in order to focus on and to exploit to the maximum the specific age-related motor learning abilities (Ricotti, 2011).

We believe that the T-test for agility has a high applicability because, like other similar test batteries, it is effective for a wide age range, from children of primary school age (Chang et al., 2013) to adolescents aged 13-16 years (Budde et al., 2008). Demonstrating their effectiveness, it will be important to promote implementation of coordinative multilateral physical education programs, which in turn can have an important impact on pupils’ health and physical fitness (Gallotta, 2014, Jarani et al., 2015).

CONCLUSIONS

Our study shows that the dynamics of the mean level of the researched indicator in the age aspect changes regressively, with the values decreasing from 1st to 12th grade, which means that the time for completion of the T-test for agility is improving. However, this improvement is only statistically significant for the increase of pupils in grade 3rd through grade 4th.

The comparative analysis of the mean values of the pupils divided by classes and gender enables us to claim that in the performance of the T-test the boys are superior to their female peers. Exceptions are the results reported for 3rd and 6th grade, where the girls are faster.

The small positive increments of the results between classes are insignificant. This, in our opinion, is due to three less well-developed components of agility: velocity ability – speed; subject agility and spatial orientation.

To improve these factors, we recommend extra working in physical education classes using the following examples: gymnastic complexes of warm-up exercises with small devices – ball, stick, rope, hoop, etc.; gymnastic moveable games with competitive character; dance movements and exercises from aerobic gymnastics.

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MODELING OF THE TRAINING PREPARATION
OF HIGHLY QUALIFIED FEMALE HOCKEY PLAYERS

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Moscow State Academy of Physical Culture,
Russian Federation & Belarusian State University of Physical Culture, Belarus

ABSTRACT
The article is devoted to the study of effectiveness of building training and competitive loads of women’s national team of the Republic of Belarus for the European Indoor Hockey Championship (Indoor Hockey). The study was conducted at a separate, three-month stage of the annual training cycle.

The Purpose of the study: To find optimal ratio between training and competitive loads using block training system for highly qualified hockey players. To achieve the goal, the following Tasks were set: 1. To determine the structure of training of Belarus national hockey players in clubs and during the training camps of the national team before the European Championship; 2. To evaluate training and competitive process as two separate areas of training for highly qualified hockey players; 3. To identify necessary volume and evaluate effectiveness of the use of non-specific loads of anaerobic orientation in shock microcycles during training process of hockey players and final result. Research hypothesis: it was assumed that control and test games, as well as non-specific loads of anaerobic orientation in shock microcycles, may have a positive effect on the efficiency of using block system for preparing highly qualified hockey players for a short-term tournament.

An analysis of the training structure of the women’s national team of the Republic of Belarus is presented from the perspective of the modern block system of periodization. Thus, it can be stated that the polycyclic principle of building the training process in Indoor hockey game sport is approved today. The obtained data on the structure of training of hockey players can be used as model characteristics.

Key words: athlete monitoring, indoor hockey, international competition, periodisation, training construction model

INTRODUCTION
Training process modeling is one of the promising areas in modern top sports (Verkhoshansky, 1985; Issurin, 2019; Kostyukevich, 2011; Antonov, 2014a; Antonov, 2014b). It is closely connected with training process building and its periodization.

An extensive experience in the training process building of highly qualified athletes has been gained in sports practice (Kostyukevich, 2011; Issurin, 2019; Antonov, 2014a; Lythe, 2008); Perrotta, Held & Warburton, 2017; Kellya, Strudwicka, Atkinsonc, Drustb & Gregson, 2020). To date, more serious studies have been carried out in cyclic sports, where the structure of the sport itself allows a precise approach to research, planning and control (Bondarchuk, 1986; Antonov, 2014b; Chavarov, Antonov, 2017; Issurin, 2012; Touretski, 1998). Acyclic sports, and sport’s games are somewhat aloof
and less studied in this regard (Zelentsov, 1985). The traditional periodization system of sports training has undergone evolutionary reform. Research in cyclic sports by Verkhoshansky (1985), Issurin (2008), Bondarchuk (1986), Turetsky (1993) has shown the effectiveness of the so-called block periodization, based on the use of highly concentrated loads, aiming at increasing the level of individual motor abilities (Bondarchuk, 1986; Verkhoshansky, 1985; Godik, 1980). In game sports, the innovators in this direction were A. Zelentsov and V. Lobanovsky (1985), whose block principle of building the training process contributed to the achievement of the first high sports results in football (Zelentsov, 1985), including the victory of Dynamo Kyiv in the Cup of Cups and in the Super cup of European Championships.

Our research focuses on field hockey, an Olympic sport with more than a century of history, and its discipline — Indoor Hockey. Field hockey, as a historical game sport, has become the prototype of all the existing types of hockey such as ice hockey, bandy, floorball, roller hockey, beach hockey, outdoor & indoor hockey.

Given the successful performance of hockey players of the national team of the Republic of Belarus at the Indoor hockey European Championship 2020 in Minsk and their gold medals, we can confidently consider the process of preparation for the continental championship as a model.

**ORGANIZATION OF THE RESEARCH**

The studies were conducted on the basis of the women’s national team of the Republic of Belarus on Indoor hockey and the Minsk Hockey Club team. The author of the article was directly involved in planning and organizing the training of the team. We analyzed training and competitive loads throughout the study period. The components of the training loads were recorded by the coaching staff of the teams. The training period under consideration was from October 28, 2019 to January 26, 2020. In the absence of a centralized training camp, all candidates for the national team were training in their clubs according to the plan presented by the head coach. Training and competition loads were monitored together with the national team coaches*. The results of volume and intensity of exercises were taken to assess the focus of the load. The wireless Polar system was used for individual heart rate control. We categorized the competitive load as mixed aerobic-anaerobic in the amount of 40 minutes per game. (Warm-up before the game and hitch after the game were not included in the volume of the competitive load).

*Control and fixing of training loads was carried out by the coaches of the national team of the Republic of Belarus Pavel Gabrinevsky and Dmitry Onachenko.

**RESEARCH METHODS**

Pedagogical observations, pedagogical control, expert assessment method, heart rate control with the Polar H7 (year of manufacture 2017). Polar H7 - heart rate sensor Compatible with iOS mobile device; iPhone 5. The sensor battery lasts 400 hours in Bluetooth Low Energy mode and when the transmission is switched on at a frequency of 5 KHz. Battery Type CR 2025. Sensor Size 34x65x10 mm, Weight 21 g. Training plans analysis, methods of mathematical statistics. Calculation of the energy focuses of the loads according to Godik M. (1980). The direct load on the athlete’s body in terms of heart rate was controlled during trainings and competitions. Training load was the main object of study. The volume and intensity of the load were recorded for its control and evaluation, according to the following indicators:

- The number of training and rest days in the microcycle.
- The number of one-time and two-time training classes per day in the microcycle.
- Total training duration (minutes).

The total assessment of the load volume
gives only an overall picture. Local load indicators were used for more precise control:
1. Number of exercises repetitions.
2. Number of athletes participating in the exercise.
3. Playing space area where the exercise was performed.
4. Individual heart rate (HR) indicators.

**RESEARCH RESULTS**

The main characteristics of the studied hockey players of Belarus National indoor hockey team are shown below. Table 1 shows the average values of the characteristics of female European champions in 2020, depending on the playing position on the field.

**Table 1. Characteristics of the studied hockey players of Belarus National indoor hockey team**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Goalkeeper (n=2)</th>
<th>Defender (n=4)</th>
<th>Forward (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>34</td>
<td>25.5</td>
<td>29.3</td>
</tr>
<tr>
<td>Q</td>
<td>7.1</td>
<td>4.8</td>
<td>4.6</td>
</tr>
<tr>
<td>V</td>
<td>20.8%</td>
<td>18.8%</td>
<td>15.8%</td>
</tr>
<tr>
<td><strong>Height (sm.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>166</td>
<td>162.2</td>
<td>166.1</td>
</tr>
<tr>
<td>Q</td>
<td>5.6</td>
<td>7.4</td>
<td>1.2</td>
</tr>
<tr>
<td>V</td>
<td>3.4%</td>
<td>4.7%</td>
<td>0.7%</td>
</tr>
<tr>
<td><strong>Weight (kg.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>68</td>
<td>61.5</td>
<td>57.8</td>
</tr>
<tr>
<td>Q</td>
<td>5.6</td>
<td>12.3</td>
<td>19.7</td>
</tr>
<tr>
<td>V</td>
<td>8.3%</td>
<td>20.0%</td>
<td>7.0%</td>
</tr>
<tr>
<td><strong>Hockey experience (years)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>22.5</td>
<td>12.3</td>
<td>19.7</td>
</tr>
<tr>
<td>Q</td>
<td>4.9</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>V</td>
<td>22.0%</td>
<td>35.5%</td>
<td>20.5%</td>
</tr>
</tbody>
</table>

Training process of the women’s national Indoor hockey team of Belarus is presented in detailed characteristics, graphs and diagrams reflecting the amount of training and competition load performed by the girls in the studied time range. The preparation and implementation period consisted of 91 days (3 full months) and was divided into three Blocks: Accumulation Block (AB), Transforming Block (TB) and Implementation Block (IB). Table 2 shows the block structure of hockey player training and the characteristics of microcycles (MCC).

**Table 2. The structure of the preparation of the women’s national team of the Republic of Belarus for the European Indoor hockey Championship on January 24-26, 2020 in Minsk (Belarus) and the characteristics of MCC**

<table>
<thead>
<tr>
<th>BLOCK</th>
<th>№</th>
<th>MCC (name)</th>
<th>MCC duration</th>
<th>Amount of days</th>
<th>Characteristics of MCC</th>
<th>Where did the players prepare</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>1</td>
<td>Preparatory</td>
<td>28.10-5.11.19</td>
<td>9</td>
<td>8</td>
<td>8 1 1 X</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Special-Preparatory</td>
<td>6.11-11.11.19</td>
<td>6</td>
<td>3</td>
<td>2 4 1 X</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Competitive</td>
<td>12.11-18.11.19</td>
<td>7</td>
<td>4</td>
<td>2 4 1 X</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Shock microcycle</td>
<td>19.11-28.11.19</td>
<td>10</td>
<td>9</td>
<td>- - 1 X</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Recovery microcycle</td>
<td>29.11-3.12.19</td>
<td>5</td>
<td>4</td>
<td>2 2 1 X</td>
</tr>
<tr>
<td>TB</td>
<td>1</td>
<td>Special-Preparatory-1</td>
<td>4.12-9.12.19</td>
<td>6</td>
<td>2</td>
<td>3 6 3 X</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Special-Preparatory-2</td>
<td>10.12-16.12.19</td>
<td>7</td>
<td>3</td>
<td>3 6 3 1 X</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Shock microcycle</td>
<td>17.12-22.12.19</td>
<td>6</td>
<td>-</td>
<td>4 - - 2 X</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Recovery microcycle</td>
<td>23.12-31.12.19</td>
<td>9</td>
<td>5</td>
<td>1 4 3 3 X</td>
</tr>
<tr>
<td>IB</td>
<td>1</td>
<td>Special-Preparatory</td>
<td>1.01-11.01.20</td>
<td>11</td>
<td>7</td>
<td>8 4 2 4 X</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Shock microcycle</td>
<td>12.01-19.01.20</td>
<td>8</td>
<td>-</td>
<td>7 1 1 1 - X</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>pre-game microcycle</td>
<td>20.01-23.01.20</td>
<td>4</td>
<td>1</td>
<td>3 3 3 - X</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>European Nations Championships</td>
<td>24.01-26.01.20</td>
<td>3</td>
<td>-</td>
<td>2 5 3 - X</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td>91</td>
<td>46</td>
<td>27 43 24 16</td>
</tr>
</tbody>
</table>
The centralized gatherings of the National team amounted to 46.7% of the entire preparation period for the European Championship. Three blocks are presented in the training structure, in which the corresponding MCC consequentially alternate. Nine of 13 MCC consisted of two workouts, or workout plus a game (or two games) per day. The distribution of rest days is noteworthy. Despite the different duration of the MCC, depending on the tasks to be solved only one day of rest was used in the MCC of the accumulation block (AB). In the transforming block (TU), the last shock and restorative MCC included 5 rest days. In the final implementation block (IB), only in the first special preparatory MCC 4 days of rest out of 11 training days were allocated. As for the shock and pre-game MCC along with the European Championship itself, they were held without taking a rest! Recovery activities took place along with two training sessions and two games per day. During this period, 2 masseurs worked with the National team.

It is noteworthy that the coaching staff used a large number of games (friendly, test and official) in 10 of 112 MCC, which indicates the importance and dynamic stability of competitive training in all units. Totally, there were 38 games, of which only 10 were national Championship games.

The block system of Belarus hockey players training for the European Championship is confirmed by the graph of the average volume of training and competition load per day, presented in Figure 1.

![Figure 1. Average amount of training and competitive load per day](image)

This indicator carries a conditional, but informational value. The diagram shows that the average amount of training load per day in each block was wave-like except the preparatory MCC (AB), the main volume of which consisted of aerobic exercises. This wave like character is due to a gradual increase at the beginning of the cycle, and a decrease at the end of the daily load volume. The volume of the average daily load from block to block was also gradually increasing from 79.9 minutes per day (AB) to 84.1 min (TB) and 113.8 min in the rest block (IB).

The wave-like volume of the load corresponded to the periodicity and cyclicity which are the basic principles of sports training. The considered three-month stage of training and
participating of the Belarus women’s team in the European Championship was an integral part of the annual training cycle for summer hockey players, and effectively fit into the overall plan for preparing both the national team and club teams for the Olympic field hockey discipline competitions.

In our opinion, the analysis of the dynamics of distribution of loads of different energy focusing is significant. Table 3 presents the characteristics of the MCC and the distribution of training and competitive loads throughout them. We have classified training loads by their energy focusing by Professor Godik, M. (1980). Each of these loads corresponds to a certain combination of load components.

![Figure 2. The ratio and distribution of total loads during the women’s national Belarus team training for the European Indoor Hockey Championship](image)

Table 3. Characteristics of training and competitive loads

<table>
<thead>
<tr>
<th>BLOCK</th>
<th>Energy orientation of the training load in (min)</th>
<th>MCC</th>
<th>Aerobic exercises, including strength</th>
<th>Anaerobic-lactic exercises</th>
<th>Exercices of anaerobic-glycolytic orientation</th>
<th>Aerobic-anaerobic exercises</th>
<th>Training load (min)</th>
<th>Competitive load (min)</th>
<th>Competitive and training load (min)</th>
<th>AVERANGE training and competition load per day at the MCC (min)</th>
<th>AVERAGE LOAD per day in BLOCK (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td></td>
<td>1</td>
<td>460</td>
<td>90</td>
<td>30</td>
<td>140</td>
<td>720</td>
<td>720</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>80</td>
<td>160</td>
<td>160</td>
<td>320</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>150</td>
<td>30</td>
<td>30</td>
<td>250</td>
<td>460</td>
<td>160</td>
<td>620</td>
<td></td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>260</td>
<td>90</td>
<td>90</td>
<td>610</td>
<td>1050</td>
<td>-</td>
<td>105</td>
<td></td>
<td>79.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>110</td>
<td>160</td>
<td>80</td>
<td>240</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>TB</td>
<td></td>
<td>1</td>
<td>70</td>
<td>-</td>
<td>-</td>
<td>60</td>
<td>130</td>
<td>240</td>
<td>370</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>225</td>
<td>-</td>
<td>30</td>
<td>290</td>
<td>545</td>
<td>240</td>
<td>785</td>
<td></td>
<td>112</td>
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<td></td>
<td></td>
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<td>-</td>
<td>-</td>
<td>290</td>
<td>420</td>
<td>160</td>
<td>580</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>IB</td>
<td></td>
<td>1</td>
<td>170</td>
<td>-</td>
<td>-</td>
<td>140</td>
<td>310</td>
<td>320</td>
<td>630</td>
<td></td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>300</td>
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<td>40</td>
<td>860</td>
<td>1300</td>
<td>40</td>
<td>1340</td>
<td></td>
<td>113</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>180</td>
<td>-</td>
<td>-</td>
<td>290</td>
<td>470</td>
<td>120</td>
<td>590</td>
<td></td>
<td>148</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>400</td>
<td></td>
<td>133</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td></td>
<td>2335</td>
<td>350</td>
<td>260</td>
<td>3700</td>
<td>6645</td>
<td>1720</td>
<td>8365</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>27.9</td>
<td>4.2</td>
<td>3.1</td>
<td>44.2</td>
<td>79.4</td>
<td>20.6</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Of interest is the analysis of the content of training loads of various focusing in the structure of the MCC and especially the distribution of the competitive load. The competitive load was one of the main means of the Belarusian women’s team players training. Its total volume amounted to 1720 minutes (43 games), which takes 20.6% of the total load (Figure 2).
In training loads, exercises of a mixed (aerobic-anaerobic) orientation-44.2% prevailed (Figure 3). These are various technical and tactical exercises performed in variable speed mode. The aerobic load (warm-up and stopping means, tactical developments, strength exercises) amounted to 28%. The percentage of non-specific anaerobic loads was 7.3%, of which anaerobic-alactate, speed-force orientation was 4.2% (350 minutes for the entire period) and anaerobic-glycolytic, aimed at developing speed endurance - 3.1% (260 minutes).

**Figure 3. The ratio and distribution of energy orientation training loads**

It is important to note the dynamics of anaerobic exercise. The bulk of high-speed non-specific work (360 min.) fell on the first Accumulating Block. In the Transformation and Implementation Blocks, the volume of such loads was three times less, 110 and 140 minutes, respectively.

**Figure 4. Dynamics of various energy focusing loads at every MMC**

All stages of preparation are clearly visible. The maximum volumes of mixed loads of aerobic-anaerobic orientation correspond to Shock MCC: in the Accumulation Block, their volume was 610 minutes, 480 minutes in the Transformational one, and 860 minutes.
in the IB. This is the main type of load, which includes specialized exercises of technical and tactical orientation, whose share in the overall structure of training was 44.2%, and in the structure of training loads was more than a half - 56% (Figure 3). Nonspecific speed-strength training and speed endurance exercises were used mainly in Shock MCC (AB-180 min.; TB-80min. and IB-140min.) It was a combination of non-specific loads of anaerobic orientation with specialized exercises of technical and tactical orientation that showed to be the shock balanced and the most effective structure for the National team training.

Assessing the structure of the daily training process for the national team players, it was interesting to compare the dependence of the average training time per day with the training and competitive loads of various energy orientation. When using the mathematical method for calculating the Pearson correlation coefficient between aerobic energy load indicators and the amount of training load per day, the correlation coefficient is +0.28; with mixed load +0.27; with anaerobic +0.24; with competitive it is negative - 0.28. Thus, to a greater extent, the amount of training load per day depends on aerobic and mixed (but not competitive) loads. Competitive loads are represented by games of international tournaments at certain stages of training, including the first accumulative block, and test games on the eve of the European Championship in the Implementation Block. The structure of competitive training is presented in Figure 5.

Figure 5. The structure of the competitive training of the women’s national team of the Republic of Belarus getting ready for the European Championship

Despite the negative correlation between the volume of daily training loads and competitive loads, we separated the latter in a standalone schedule. From December 4 to January 23, the Belarus national team players played 31 games plus 5 games of the European Championship itself. Of these, they played 10 games as part of club teams at the national championship games, 21 games as part of the national team (international tournaments in Poland, Russia and Austria) and 4 test games on the eve of the continental championship in Minsk.

An analysis of the Republic of Belarus
women’s national team training structure is presented from the perspective of a block system of periodization. Thus, we can state that the polycyclic principle of building the training process in game sports is currently approved. The women’s national team of the Republic of Belarus performance at the European Championship exceeded expectations. The team, led by Dutch specialist Herman Kruis, became the champion of Europe for the first time in its history.

CONCLUSIONS
1. The proposed training structure for the women’s national team of the Republic of Belarus can be considered as a model of preparation for the European Championships and World Cups.
2. The polycyclic training process building based on the block system is an effective means of preparation in the Indoor Hockey as a game sport.
3. The general Indoor Hockey teams training plan (as a game sport training) for important tournaments such as the European Championship and the World Cup should be considered from two perspectives: a. Training process planning; b. Competitive training planning.
4. The combination of non-specific loads of anaerobic orientation with specialized technical and tactical exercises has formed the basis of shock MCC of accumulative and implementation blocks and effectively fit into the national team training structure for the European Championship.
5. The average amount of training load per day in each block is wave-like. This is due to gradual increase at the beginning of the cycle, reaching maximum in the middle, and decreasing of the daily load volume at the end of the cycle.

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ABSTRACT

Football is an intermittent sport with a great number of short and explosive actions. These characteristics of the game require a good level of anaerobic power. The main field tests used as indicators of the development of the anaerobic energy system were the jumps in the vertical plane. The same tests also measured the strength of the lower limbs. We presume that the explosive power of the lower limbs characterizes the development of the alactic anaerobic energy system and strength capacity at the same time. In that case the explosive power of the lower limbs was an important component of the conditioning and strength training of football players. There was a great variety of methods and devices which registered vertical jump height. From this point of view, we wanted to add our study to the research work in the specialized literature. The purpose of this study was to analyze the differences of the jump height measured via two devices. We used the following methods of research: accelerometry, chronometry and statistical analysis. We studied the vertical jump height of 32 football players of the Youth Academy of PFC “Levski” – Sofia at the age of 13,4. In the research the participants performed three jump tests (squat jump [SJ], counter movement jump [CMJ] and counter movement jump with arm swing [CMJA]) as the jump height was measured via accelerometer and Infrared platform. The results from these two devices were compared via Bland Altman plot and calculation of Intraclass correlation coefficients [ICC]. The results of ICC between the two devices showed very strong correlation of the results for the three tests (SJ (R= .91), CMJ (R= .92) and CMJA (R= .87)). The results of the ANOVA showed statistical difference between the measured jump heights (p< .05 for all test, systematic bias was equal to: SJ=15.6; CMJ=15.2; CMJA= 19.5 and effect size (η²) was large SJ=.65; CMJ=.69; CMJA=.65) for the three different types of jump. Conclusions: 1) Both of the devices showed good consistency of the collected results; 2) The data collected from the two devices showed significant difference of the jump heights.

Key words: football, vertical jump, team sports, testing, validity.

INTRODUCTION

The explosive power of the lower limbs is an important component of conditioning and strength training. The character of the game predetermines great requirements on anaerobic explosive actions (Di Salvo et al., 2013). It is known that explosive power is related to the maximal speed and acceleration capability (Nordin et al., 2014; Peev, 2014; McFarland et al., 2016; Rouis et al., 2016). At the same time, a great number of sport professionals specify the quantitative values of explosive
power as a method for control, selection and prediction of capabilities of the young players (Klavora, 2000; Markovic et al., 2004; Cunha et al., 2017). Some authors even offer indirect assessment of anaerobic power based on the values of jump height (Hoffman and Kang, 2002; Balsalobre-Fernandez et al., 2014; Lafaye et al., 2014).

The vertical jumps were reliable and popular tests for determining the explosive power of the lower limbs of athletes. At the same time, they were tests which measured the muscle strength of different muscular efforts (concentric, eccentric and the stretch-shortening cycle muscle function). Other frequently used tests were the squat jump [SJ], the counter movement jump [CMJ] and the counter movement jump with arm swing [CMJA] (Kibele, 1998; Enoksen et al., 2009). The establishment of the jump height in test exercises was done by various devices and methods such as contact plates, force plates, infrared platforms, linear position transducer, accelerometer and video analysis (Hatze, 1998; Haugen et al., 2013; Klavora, 2000; Markovic et al., 2004; Nordin et al., 2014). Based on this variety of methods and devices, our desire was to help for the proper understanding of this problem. There are many surveys (Garcia-Lopez et al., 2005; Leard et al., 2007; Moir et al., 2008; Buckthorpe et al., 2012; Monnet, 2014) which compare different methods and devices but in our research we used devices which had not been studied before. Another novelty for science is the type of research with young football players which, to our knowledge, has not been done so far. It will be extremely useful for analysis and correct comparison of the results from these tests for physical education teachers and conditioning specialists. As Haugen et al. (2013) observe there was no progress in the jump height between 1995 and 2010 but at the same time the sprinting speed increased slightly. In this line of thought, there were reserves in the jumping performance of football players that physical education teachers and conditioning specialists could exploit. Both Rampinini et al. (2007) and Haugen et al. (2013) came to the same conclusion about elite and non-elite players. As we mentioned above, there is a relationship between sprinting and jumping performance and it is unlikely for individuals with poor leg explosive power to meet modern football requirements completely.

The development of technology has led to greater precision of the devices used. In general, this research wanted to verify and double check this problem and, in addition to previous research, to investigate the concurrent validity of the two devices that were previously mentioned. Another focus of our research was to find a model for transforming the device results, because we could not find papers or equations on this matter in the existing literature.

All these considerations led to the purpose of our study, which was to investigate the concurrent validity and reliability of devices for measurement of the jump height.

The objectives of the present study were:
1. To establish the average jump height among different devices that measured vertical jump performance;
2. To specify the relationship between the results of the two devices for measuring the vertical jump performance and their respective differences;
3. To create a model for comparison of the results of the two devices that measured vertical jump performance.

METHODS
Study design
Our research wanted to give answer to the question about the concurrent validity of two
measurement devices that register jump height. We didn’t use gold “standard” devices because we did field testing and they were not appropriate for that kind of research. Both devices were simultaneously used on a specific subject so we could compare the results via both devices. In order to solve the assigned tasks, we used the following methods of research: accelerometry, chronometry which had been integrated in the two devices (G-walk sensor and Infrared platform) At the end we summarised the received and made statistical analysis with the following methods: descriptive statistic, Shapiro-Wilk normality test, Intraclass correlation, ANOVA and Bland-Altman plot.

**Subjects of the research**

The tested subjects of our research were 32 (162.6 ± 8 cm; 49.5 ± 6.3 kg) adolescent football players from Youth Academy of PFC „Levski”– Sofia at the age of 13.4 with at least 4 years of training experience.

Voluntary informed consent was obtained from all players before the study began. Ethics approval for the tests was granted by the University Human Research Ethics Committee. Written permission from the club and the parents was received to record and analyze the data.

**Instruments**

The jump height was recorded using a 200 Hz inertial G-Walk sensor (BTS Bioengineering, Italy) and Infrared platform (IR) - OptojumpNext (Microgate, Bolzano, Italy) with a capture frequency of 1000 Hz. The device (G-walk) had integrated in it a tri-axial accelerometer (with sensitivity ± 1.5 - ± 6 g), a tri-axial magnetometer, and a tri-axial gyroscope (with sensitivity ± 300 - ± 1200 gps). These microsensors allowed it to detect and record accelerations and vertical displacement of the centre of mass [CM]. All the data were sent via Bluetooth to a personal computer with installed special software (BTS G-Studio) where all the calculations were made. The data of IR were obtained from the photoelectric cells built in 1-meter-long parallel bars (receiver and transmitter). The transmitter contains 100 diodes emitting infrared light, positioned 3 mm from ground level at 10 mm intervals. The system measures the flight time of a jump with a frequency of 1/1000 seconds (1 kHz). The Optojump bars were connected to a personal computer with the proprietary software which instantly provides the measured outcomes. The Optojump Next software calculates the height of vertical jump based on flight time using the formula ((g*flight time^2)/8) described by Bosco et. al (1983) (where g is gravitational acceleration that is equal to 9.81 m/s^2). The Optojump bars were placed 2 m apart parallel to each other on a flat surface.

**Procedures**

Detailed descriptions of the execution of the test are explained in the following paragraphs and are graphically presented in Figure 1:

**Squat Jump** was performed from a starting position with a flexion at the knee joint approximately at 90 degrees with visual confirmation. The feet were shoulder width apart with plantar part of the feet contacting the ground and the hands were on waist throughout the exercise. The trunk was erected. From this position, the legs were extended quickly with maximum power in order to reach maximum height. The lower limbs were extended until the landing (Figure 1 A). We use this test to check the concentric muscle power of the lower limbs.

**Counter Movement Jump** was executed from a standing starting position. The feet were shoulder width apart plantar part of the feet contacting the ground and the hands were on the waist throughout the exercise. From this position a quick flexion at the knee
joint approximately 90 degrees with visual confirmation (main goal was to do a rapid downwards movement) followed by extension of the lower limbs and jump upwards with the goal of achieving maximum height. The lower limbs were extended until the landing (Figure 1 B). With this test we wanted to reveal the stretch-shortening cycle muscle function, as it is closer to a match-playing situation.

Counter Movement Jump with Arm Swing was executed from a standing starting position. The feet were shoulder width apart and the hands were lifted above the head. From this position a quick flexion on the knee joint approximately 90 degrees with visual confirmation in coordination with rapid lowering of the arms (Figure 1 C-2). This movement was followed by extension of the lower limbs in coordination with swinging motion of the arms up (Figure 1 C-3) and a jump upwards with the goal of achieving maximum height without lowering of the arms. The lower limbs were extended until the landing (Figure 1 C-4). The test helps us to find the muscle power of the lower extremities in condition that are as close as possible to playing in a football match.

Testing was conducted at the end of the competitive season within one day. The tests took place in a single session with simultaneous use of both measuring devices. The athletes were introduced to the testing procedures and techniques prior to the examination as a part of their usual testing battery. The testing battery included: Vertical jump tests (made in this order SJ, CMJ and CMJA), Sprint test (20 m dash running), Aerobic capacity test (Vameval test) and technical tests (dribbling, jogging and passing). In this research we used only the jumps test results.

The football players did the tests after a standard warm up consisting of 6 minutes riding an exercise bike, dynamic stretching, squatting and two test tries without their registration or measuring devices. The test was conducted in an indoor facility with a flat floor. The players stood in a closed space restricted by the side bars of Optojump, which created a coordinate system, and wore their waist belts with accelerometers attached in a specially designed pocket. Every player was verbally supported and instructed to jump as high as he could. The three tests were conducted one after another in this order: SJ, CMJ and CMJA. We used three tests SJ, CMJ and CMJA in that order to standardize the results and eliminated the errors and difference in performance caused by fatigue. The players did two trials with the devices in every type of jump and we used the better one. All subjects of the research rested for 30 second between the trials. The right execution of the jump was observed visually and that was a condition for continuing with the next jump.

Statistical analysis

Descriptive statistics was used to receive the average value (X) and standard deviation (SD) of the jump height for all of the above-mentioned tests. We used the Shapiro-Wilk normality test to define the normality of the received data. When we proved the normality, we used the ICC to define the interrelationship of the results for every participant in the tests. We compared the results of the jump height using ANOVA, with the alpha level set at p < .05, to identify the measurement differences of the two devices and at the end we illustrated them graphically with the Bland–Altman plot.

All statistical procedures were done using SPSS Statistics ver. 19 software (IBM Corp., Armonk, NY). The procedures were made according to Damyanova (2012).
RESULTS

The results of the descriptive statistics of the jump height in different types of jumps can be seen in Table 1. The coefficient of variation [CV%] for the measured parameters with both measuring devices was between 12.00% and 16.20%, which defines the research parameters with middle dispersion.

Table 1. Variability of the parameter jump height in different types of jumps measured with inertial system (G-Walk) and infrared platform (Optojump Next).

<table>
<thead>
<tr>
<th>Methods of study and values for individual modes of implementation</th>
<th>Inertial sensor (G-Walk)</th>
<th>Optical platform (OptojumpNext)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SJ</td>
<td>CMJ</td>
</tr>
<tr>
<td>Mean</td>
<td>44.66</td>
<td>45.22</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>1.03</td>
<td>0.96</td>
</tr>
<tr>
<td>Median</td>
<td>44.60</td>
<td>46.05</td>
</tr>
<tr>
<td>Mode</td>
<td>43.80</td>
<td>41.80</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>5.84</td>
<td>5.44</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.123</td>
<td>-0.653</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.318</td>
<td>0.595</td>
</tr>
<tr>
<td>Range</td>
<td>27.20</td>
<td>23.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>31.40</td>
<td>31.70</td>
</tr>
<tr>
<td>Maximum</td>
<td>58.60</td>
<td>54.70</td>
</tr>
<tr>
<td>CV%</td>
<td>13.1</td>
<td>12.0</td>
</tr>
</tbody>
</table>
Skewness [As] and Kurtosis [Ex] are respectively in range between 0.014 to -0.766 and -0.321 to 1.060 (with critical values for all tested subjects (n = 32) As = 0.854 and Ex = 1.665), which defines the tested parameter as normally distributed. The normality of the results was reconfirmed from Shapiro-Wilk test of normality (p > .05).

The results in table 1 received from the accelerometer were higher than the results of the IR with systematic bias of: SJ = 15.6 cm; CMJ = 15.2 cm; CMJA = 19.5. The effect size(η²) was large for the three tests and equals to: SJ = .65; CMJ = .69; CMJA = .65.

The normality of the distribution of the jump height for both measuring devices from Shapiro-Wilk test of normality and coefficients of As and Ex allowed us to use the, ICC, ANOVA and Bland - Altman plot.

We made ICC of all of the results and we achieved strong consistency of the results between the two measurement devices. The relationship between SJ_{(G-walk)} and SJ_{(IR)} was R = .91 (p < .05) with limit of agreements [LA] in range of 0.81-0.96. The correlation between CMJ_{(G-walk)} and CMJ_{(IR)} was R = .92 (p < .05) with LA in range of 0.84-0.96. The lowest level of correlation was between CMJA_{(G-walk)} and CMJA_{(IR)} that was R = .87 (p < .05) with LA in range of 0.68-0.93.

We could observe important differences between the results of the two measuring devices when we performed ANOVA for SJ (F₀.05<F_{emp.} =156.7), CMJ (F₀.05<F_{emp.} = 154.9) and CMJA (F₀.05<F_{emp} =135.2). These differences were graphically presented through the Bland-Altman plot (Figure 2, Figure 3 and Figure 4) on the reliability of the measured parameters with the two devices. The upper and lower lines represent 95% confidential interval with means ± 1.96 SD of the differences (SJ_{LA}: 9.92-21.37 cm; CMJ_{LA}: 10-20.25 cm; CMJA_{LA}: 10.56-28.35 cm).

**Figure 2.** Bland-Altman plot between the OptojumpNext IR platform and G-walk accelerometer in the Squat Jump test
In order to apply our theoretical knowledge into practice we made a linear regression model of the results of the three tests (Table 2). This way we can transform the result from the IR device and predict the values of the G-walk accelerometer.

Table 2. Linear regression equations for calibration of the results of the IR to G-walk

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Regression equation</th>
<th>Fisher criterion</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ (IR)</td>
<td>SJ (G-walk)</td>
<td>y=1.3052x+6.7926</td>
<td>115.3</td>
<td>.001</td>
</tr>
<tr>
<td>CMJ (IR)</td>
<td>CMJ (G-walk)</td>
<td>y=1.1313x+11.234</td>
<td>103.5</td>
<td>.001</td>
</tr>
<tr>
<td>CMJA (IR)</td>
<td>CMJA (G-walk)</td>
<td>y=0.9289x+22.078</td>
<td>43.7</td>
<td>.001</td>
</tr>
</tbody>
</table>
DISCUSSION

Our research had similar results and, as we hypothesized, there were differences in the jump height of devices that used different methods for its calculation. Every manufacturer assured the reliability and validity of their system with force plate measures – the golden standard in this type of measurements (Hatze, 1998). This method used the ground reaction forces of the contact time of the take-off to calculate the height of the jump. Other authors, such as Aragón-Vargas (2000), stated that the golden standard should be video analysis. Different systems use various methods such as flight time, length of a pulled cord or rope, video analysis, vertical displacement of CM or the velocity of taking-off of CM. A great number of surveys were made in this manner using various measuring devices, which caused greater variation of the results. The most frequently used method for measuring jump height is based on the flight time mainly because it is easily accessible, even though many authors find some limitations of this method (Markovíc et al., 2004; Enoksen et al., 2009; Requena et al., 2012; Nordin et al., 2014).

According to Bosco et al., (1983), Hatze (1998), Kibele (1998), Aragon-Vargas (2000), Moir (2008), Enoksen et al. (2009) these differences and limitations are expressed as follows:

It is presumed that the upward and downward part of the flight time are of equal length, which is not correct;

Landing in a different place from the take-off place means greater flight time, therefore higher result;

From biomechanical point of view, the lower limbs are more flexed during the landing rather than the take-off.

The other method that we used in this research is based on the accelerometer data. The main disadvantage of measuring jump height by the velocity of the take-off of CM was that the highest velocity was reached prior to the jump itself (Hatze, 1998; Enoksen et al., 2009). Another main difference which we could observe and was also in agreement with other research was the statistically valid difference between the results of all the tests for both measuring devices. The results acquired in our research were similar to those stated in other research papers. The main argument we could give was that the accelerometer overestimates the received result, while the infrared platform underestimates it (Bosco et al. 1983; Aragon-Vargas, 2000). The results by Moir (2008) were not in agreement with the previous findings. However, most authors reported lower values for the results when the flight time method was used as a measuring technique (Markovic et al., 2004; Slinde et al., 2008).

The method of measuring the vertical displacement of CM was also verified and thought to be appropriate according to the data collected by various authors (Nuzzo et al., 2004; Cronin et al., 2011; Buckthorpe et al., 2012; Choukou et al., 2014). However, some authors thought that its accuracy was questionable (Aragon-Vargas, 2000; Moir, 2008; Enoksen et al., 2009).

All of these devices and methods had one main goal – increasing the measuring accuracy of the parameters which determine explosive power. The most accurate measuring device was still not specified, however there were two of them widely accepted with time and practice: video analysis and force plate. Unfortunately, the majority of the measuring in the field was done with other, less expensive and more user-friendly measuring devices. The reasons for that were as follows: firstly, these platforms were expensive and could mostly be found in laboratories and secondly – there was the need for quick and easy data collecting during field work.

From our findings we could conclude that the measuring devices register concurrent validity on the three of the tests. The strong cor-
relational coefficients between two the measurements (R=0.87 – 0.92) on the same tests proved it. Despite a significant difference in measuring the parameter both systems could identify better and worse results. ICC varied across different authors which we related to the different measuring devices and their accuracy.

In sports theory we could find different tests that were used for measuring jump height (or in other words vertical displacement of CM) (Aragon-Vargas, 2000; Markovic et al., 2004; Enoksen et. al., 2009; Nordin et al., 2014). However, SJ, CMJ and CMJA were the most frequently used ones (Requena et al., 2012; Attia et al., 2017). The results from these tests are influenced by four main parameters of execution (Cheng et al., 2008). The first one is linked to the usage of arms and their movement (Cheng et al., 2008). The second one is about the depth of the squat. The deeper the squat the higher the result, because of the preliminary stretching of the muscles (Gheller et al., 2014; Laffaye et al., 2014). The third one is the position of the lower limbs while in the air, because if we lift them, we could achieve a greater result. The fourth one is about the same position of take-off and landing, because if you landed at a different place this would mean that you did not jump only in the vertical plane (Markovic et al., 2004; Glatthorn et al., 2011).

The method integrated in Optojump-Next (flight time method) was validated by Garcia-Lopez et al., (2005), Glatthorn et al., (2011), and Attia et al., (2017). The researchers must have in mind that the actual jump height is by 0,3 cm greater than the received one because the sensor is 0.3 cm above the surface on which the bars are situated. Other research by Balsalobre-Fernandez et al., (2014) and Magrum et al., (2018) showed that the infrared platforms are a reliable source of information for the sports scholars.

Our results were similar to Balsalobre-Fernandez et al., (2014). These authors found that OptojumpNext has theoretical precision usually ±1.8 mm, but it should be decreased in proportion with the increase of the jump height. However, the current Bland-Altman plots with the regression lines show that higher jumps correspond to larger differences between devices.

Similar surveys about the validity and reliability of tests have been done by numerous authors with different systems and devices as well as different methods of determining the jump height (Bosco et al., (1983); Aragon-Vargas, (2000); Hoffman and Kang, (2002); Leard et al., (2007); Szmuchrowski et al., (2007); Borges Junior et al., (2011); Buckthorpe et al., (2012); Balsalobre-Fernandez et al., 2014; Monnet et al., (2014); Słomka, (2017)). The result of SJ and CMJ presented in Table 1 allowed us to conclude, that despite being the same age young football players exhibit different skills when it comes to using the elastic forces of the extending muscles of the lower limbs. Our results are a proof to this statement because the difference between these jump heights must be greater for CMJ compared to SJ (Bobbert et al., 1996) In our case it was just around 1 cm. Other scientists had come to similar conclusions (Brown et al., 2001; Peev et al., 2017). Also, some authors took into account the more accurate measuring of SJ rather than CMJ (Enoksen et al., 2009).

The difference between CMJ and CMJA is the same as reported in the literature, between 20-21% for different measuring devices (Slinde et al., 2008). We must consider the fact that most of the football players cannot efficiently use the arm swings (Miladinov, 1998). Evidence for these conclusions is the greatest range of the presented jump height in Table 1 of this test for both devices.
It also has to be taken into consideration that during the tests the CM increases by up to 4 cm with the lifting of the arms, while the belt with the accelerometer is fixed on the waist and this type of increase is impossible (Monnet et al., 2014).

STRENGTHS AND LIMITATIONS
The main contribution of the research is the regression models for comparing the results of the IR and G-walk devices. In general, this research confirms the results of other similar reports that the accelerometer method shows greater value of the jump height. As a limitation of the research we can point the lack of a test-retest method for validity of the measured results which can be a direction for future research.

CONCLUSIONS
Based on the results of this study, the following conclusions were drawn as recommendations for the sport practice:

The two devices have good consistency of the collected results;

The data collected via two devices showed significant difference of the jump heights.

RECOMMENDATIONS
Scientific research or monitoring the trends of development of explosive power in sport should be done by using a single method. Comparison of values and data in the scientific literature derived by using different methods and devices must be used with caution.

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ANALYSIS OF THE DEPENDENCE BETWEEN JUMPING TAKEOFF AND ANTHROPOMETRIC INDICATORS OF FEMALE FIGURE SKATERS

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ABSTRACT
Jump Elements in figure skating are an integral part of motor activity. One of the conditions for their good performance is great height and length. Criteria for this are the indicators of speed and power qualities.

The aim of this research work is to analyze the relationship between anthropometric indicators and those for jumping takeoff of young female figure skaters of the basic level of training. Seventeen female skaters aged 10-14 years old (prepuberty) from ice skating clubs in Bulgaria voluntarily participated in the study. The age of the participants was 10 to 14 years old, which is considered favorable for the development of speed and strength abilities. They were subjected twice to 8 anthropometric measurements and 5 different types of takeoff, conducted in off-ice conditions. To achieve the goal of the survey, the following research methods were used: theoretical analysis and generalization of data in specialized scientific and methodological literature, pedagogical observation, pedagogical testing, anthropometric research methods and methods of mathematical statistics for processing the results of the study.

The results showed significant intragroup dependences for the anthropometric and biomechanical parameters for all types of jumps takeoff in the first study and a decrease in the correlation coefficients in the second measurement. The maximum force in all types of jumps increases with increasing indicators of height, weight, length of the lower limbs, chest circumference, shoulder width, while the width of the pelvis does not affect the strength of the takeoff. The height of the jumps with the help of the arms depends on the width of the shoulders – $r = .497$, and for vertical jump with the hands on the hips – $r = .664$.

Key words: figure skating, anthropometric indicators, speed-force parameters.

INTRODUCTION
Modern figure skating has reached a very high level of technical mastery. Victory in high-ranking competitions is achieved only by athletes whose arsenal includes the most technically complex elements of figure skating. Achieving the desired result is possible only if you demonstrate these elements during the competition.

The main trends in the development of programs in the individual disciplines of figure skating are the complexity of the jumps, their combinations and series, the aspiration of the skaters to diversity, balance and artistic design (Lysova, 1997). Jumping takes a leading place in the programs of every highly qualified figure skater, because they have the greatest impact on the final result in competitions.
Nowadays, skaters learn the most complex jumping elements in adolescence. Only 15-20 years ago, in top-level competitions, the triple Axel and quadruple jumps were performed only by the top five best skaters in the world. Nowadays we are witnessing the performance of quadruple jumps not only by men but also by women. In order to achieve high results when performing multi-turn jumps, the modern training process must be aimed at improving their quality and increasing the amount of revolutions performed during the flight. This can be achieved by increasing the height and length of the jump, as well as the initial angular velocity of the bounce, followed by the rapid grouping of body parts in flight. All this, above all, requires a high level of development of speed and power qualities.

Figure skating is a sport that combines endurance, strength, flexibility and grace with a touch of artistry. The high level of discipline forces more and more young athletes to train outside the standards considered safe for a young, growing body (Porter, Young, Niedfeldt, Gottschlich, 2007). As it is one of the early specialized sports (American Academy of Pediatrics (AAP), 2000); monitoring training effects and physical development, performing and evaluating anthropometric measurements and physical fitness tests regularly in and out of group comparisons can be useful for monitoring performance.

Physical morphology or physique, including body mass or composition, size and shape, is important to optimize athletic performance in many sports (Slater, O’Connor, & Kerr, 2018; Durakovic, 2012). The results of some studies suggest that figure skating favors lightness, leanness, higher mesomorphy and lower endomorphy at more elite levels (Monsma, & Malina, 2005). Mesomorphic type of the figure is characterized by proportional body size and harmonious development of the musculoskeletal system. The higher degree of mesomorphy is associated with good physical capacity and greater development of the explosive force of the lower extremities (Toteva, 1992). The study of Paluchowska M. (2015) found that female figure skaters are relatively shorter and lighter than their non-sports peers, which suggests a greater influence of sports-training factor on growth than genetic factors. The lower the athlete’s weight, the less energy he or she has to put into performing certain elements (such as jumping). However, it is known that athletes with relatively low body weight and height have better results in figure skating. Elite sporting performance is the result of the interaction between genetic and training factors, with the result that both talent identification and management systems to facilitate optimal training are crucial to sporting success (Tucker, & Collins, 2012).

The goal of the study is to analyze the relationship between anthropometric indicators and those of the jumping takeoff of skaters.

MATERIALS AND METHOD
To achieve the goal of the study, we set the following tasks to solve:

- Measurement of anthropometric indicators of the skaters.
- Measurement of speed and power indicators with BTS G-sensor equipment.
- Calculation of body mass index.
- Establishing a correlation between anthropometric parameters and those for jumping abilities (takeoff).

The subject of the study is the dialectical relationship between parameters of the anthropometric features and speed-strength readiness in the jump elements by the young figure skaters.

The object of the research are the measurements of the anthropometric factors and speed-power indicators of the skaters.

The following research methods were
used to solve the set tasks:

- Analysis and summarization of the scientific literature.
- Pedagogical supervision.
- Sports-pedagogical testing: anthropometric medical measurements; instrumental methods.
- Math statistical methods.

**Participants**

Seventeen figure skaters with a basic level of preparation aged 10 to 14 (before puberty) from Ice Skating Clubs in the Republic of Bulgaria voluntarily participated in the study. All participants are competitive figure skaters who annually participate at National Championships and International tournaments from the ISU calendar in single categories from Basic Novice to Juniors. All of them can execute all double jumps (except double Axel).

**Organization of the research**

To solve the tasks, research was organized and conducted between 2015 to 2017 in the Center for Research and Applied Activity in Sports, in the Department of “Anatomy and biomechanics” of the National Sports Academy “Vassil Levski” and in the Winter Sports Palace.

To obtain current and cumulative information about the latent state and dynamics of development of the individual signs and components of the studied subjects’ motor abilities, we used a test battery (Table 1).

<table>
<thead>
<tr>
<th>№</th>
<th>Measured parameters</th>
<th>Measure units</th>
<th>Measurement accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Body height</td>
<td>[cm]</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>Body weight</td>
<td>[kg]</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>Chest Volume</td>
<td>[cm]</td>
<td>0.1</td>
</tr>
<tr>
<td>4, 5</td>
<td>Length of right and left lower limbs</td>
<td>[cm]</td>
<td>0.1</td>
</tr>
<tr>
<td>6, 7</td>
<td>Shoulder width, pelvis width</td>
<td>[cm]</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>Foot length</td>
<td>[cm]</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>№</th>
<th>Measured parameters</th>
<th>Measure units</th>
<th>Measurement accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Squat Jump</td>
<td>[cm, kN, m/s]</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>Counter Movement Jump</td>
<td>[cm, kN, m/s]</td>
<td>0.01</td>
</tr>
<tr>
<td>11</td>
<td>Counter Movement Jump with arms rush</td>
<td>[cm, kN, m/s]</td>
<td>0.01</td>
</tr>
<tr>
<td>12</td>
<td>Drop jump</td>
<td>[cm, kN, m/s]</td>
<td>0.01</td>
</tr>
<tr>
<td>13</td>
<td>20 repeated jumps</td>
<td>[cm, kN, m/s]</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The measurements were conducted twice: July 2015 and August 2017. Participants were wearing light clothing and no shoes during measurements. To study the peculiarities of the physical development of young skaters and analyze the relationships between the individual characteristics of body structure and athletic success, we conducted anthropometric measurements. The study of anthropometric features is associated with sports typology. It informs about the state of physical development and the ergonomic anthropometric characteristics of the athletes. The anthropometric profile of athletes of a certain sport provides information about the specific morphological selection, as well as the impact of this sport on the measurements and body development of the athlete. We measured somatometric parameters:
body height, body weight, chest volume, lower limb length, shoulders width, pelvis width, foot length (parameters 1–8). Body length (height straight) – measure the distance from the floor to the highest point of the head (vertex) in cm to the nearest 1 mm with a Martin-type metal anthropometer with a scale length of no less than 2.1 meters by the method of MARTIN. To measure the shoulder and pelvis width and foot length a spreading caliper with an accuracy of 0,5 cm was used. Chest volume and length of the lower limbs were measured to the nearest 0,1 cm with the Lufkin W606PM tape measure, which passes behind at the lower corner of the shoulders, and beneath the chest in front. Length of lower limb (“standing still”) – measured by the distance from the back of the iliac anterior superior to the floor with precision up to 1 mm. The body weight was measured with calibrated electronic weighing scale with a precision of 0,1 kg. The measurement of the larger dimensions of the body is presented in a standing position. The body mass index (BMI) is a value derived from a person’s weight and height. BMI is defined as body mass divided by squares of body height and is universally expressed in units of kg/m$^2$, resulting in weight in kilograms and height in meters.

With the help of instrumental methods, we researched on the explosive force of the lower limbs and the jumping efficiency (tests 9-13), for which we used the accelerometer equipment “BTS G-sensor”. The equipment is a methodology for studying various parameters that can be realized and observed during a certain type of jump.

The BTS G-sensor is a wireless system consisting of a device that has a built-in three-dimensional accelerometer, gyroscope and magnetometer, which is connected wirelessly to a computer. Through them the device calculates and records any change in the position of the body of the examined person. The BTS G-sensor is easy to use. The sensor is placed around the athlete’s waist, attached to an ergonomic belt that allows freedom of movement. The athlete can jump freely, change direction and run short distances. The sensor connects to the computer via Bluetooth at a distance up to 20 meters.

When the test is completed, an automatically generated report shows all recorded spatial-temporal parameters: strength and power; and allows comparison of experiments.

Jumping tests were performed to measure the following parameters: jump height [cm]; maximum force [kN]; maximum velocity [m/s]; takeoff speed [m/s], calculated time [s] and acceleration [m/s$^2$]. All data were recorded in separate protocols for each competitor.

**Data analysis**

For analysis of the results we used mathematical-statistical methods: descriptive statistics, correlation analysis and comparative analysis using Student’s T-criterion for dependent samples with statistical the software package IBM SPSS STATISTICS v22 and MS Office 2018.

A. Descriptive statistics – to establish the variability of the studied indicators:

Calculation of sample’s mean ($\bar{X}$). The mean of the variable $X$ is defined by the equality: $\bar{X} = \frac{\sum X}{n}$, $n$ is the number of studied objects.

Standard deviation $S$ – an indicator that is a function of all observed values of $X$ in the sample and carries the most complete information about the degree of scattering of $X$ in the sample.

Calculated by the formula: $S = \sqrt{\frac{\sum (X-\bar{X})^2}{n-1}}$.

Coefficient of variation $V$ – in percent, which characterizes the homogeneity of the studied population and is calculated by the formula: $V = \frac{S}{\bar{X}} \cdot 100(\%)$.

B. Correlation analysis is used to evaluate the strength of the relationship between quantitative variables. The analysis compares the correlation coefficients between one or more
pairs of variables to establish statistical relationships between them.

C. Comparative analysis with Student’s t-test – to accept or reject the null hypothesis, regarding the observed differences between the mean levels of the studied traits both between the two participating in the experiment (at the beginning and end of the period) and between the initial and final state of each of these aggregates.

RESULTS AND DISCUSSION

The descriptive statistics of the anthropometric indicators in the first and in the second measurement (Tables 2 and 3) gave us low values for the coefficients of variation, asymmetry and excess. The coefficient of variation of all indicators was up to 17%, which is an indicator for a homogeneous sample and normal distribution of data from the sample. The established normal distribution gave us grounds to make a comparative analysis of the studied sample using Student’s T-criterion for the dependent samples, due to the fact that the same contingents of the research individuals were compared.

Table 2. Descriptive statistics of the anthropometric variables – first measurement

<table>
<thead>
<tr>
<th>Variables</th>
<th>S</th>
<th>V%</th>
<th>As</th>
<th>Ex</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height [cm]</td>
<td>147.23</td>
<td>6.55</td>
<td>4.45</td>
<td>0.158</td>
<td>-1.021</td>
<td>158.40</td>
<td>138.00</td>
</tr>
<tr>
<td>Body weight [kg]</td>
<td>37.38</td>
<td>6.02</td>
<td>16.11</td>
<td>0.509</td>
<td>-0.741</td>
<td>47.80</td>
<td>28.40</td>
</tr>
<tr>
<td>Chest vol. [cm]</td>
<td>64.69</td>
<td>4.27</td>
<td>6.60</td>
<td>0.270</td>
<td>-0.615</td>
<td>73.00</td>
<td>58.00</td>
</tr>
<tr>
<td>Length of right l. [cm]</td>
<td>85.01</td>
<td>5.34</td>
<td>6.28</td>
<td>0.817</td>
<td>-0.021</td>
<td>95.60</td>
<td>77.10</td>
</tr>
<tr>
<td>Length of left l. [cm]</td>
<td>85.12</td>
<td>5.13</td>
<td>6.03</td>
<td>0.954</td>
<td>0.290</td>
<td>95.80</td>
<td>78.50</td>
</tr>
<tr>
<td>Shoulder width [cm]</td>
<td>32.94</td>
<td>2.04</td>
<td>6.19</td>
<td>0.817</td>
<td>-0.021</td>
<td>36.50</td>
<td>29.50</td>
</tr>
<tr>
<td>Pelvis width [cm]</td>
<td>22.65</td>
<td>1.98</td>
<td>8.75</td>
<td>0.210</td>
<td>0.045</td>
<td>26.50</td>
<td>19.00</td>
</tr>
<tr>
<td>Foot length [cm]</td>
<td>22.50</td>
<td>1.33</td>
<td>5.93</td>
<td>0.760</td>
<td>0.207</td>
<td>25.50</td>
<td>20.50</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>17.17</td>
<td>1.87</td>
<td>10.90</td>
<td>0.533</td>
<td>0.136</td>
<td>21.31</td>
<td>14.15</td>
</tr>
</tbody>
</table>

Table 3. Descriptive statistics of the anthropometric variables – second measurement

<table>
<thead>
<tr>
<th>Variables</th>
<th>S</th>
<th>V%</th>
<th>As</th>
<th>Ex</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height [cm]</td>
<td>155.66</td>
<td>6.11</td>
<td>3.92</td>
<td>-0.428</td>
<td>-1.353</td>
<td>163.40</td>
<td>146.00</td>
</tr>
<tr>
<td>Body weight [kg]</td>
<td>46.26</td>
<td>7.89</td>
<td>17.05</td>
<td>0.838</td>
<td>-0.206</td>
<td>64.00</td>
<td>37.50</td>
</tr>
<tr>
<td>Chest vol. [cm]</td>
<td>69.44</td>
<td>4.16</td>
<td>5.99</td>
<td>1.289</td>
<td>2.657</td>
<td>81.00</td>
<td>64.00</td>
</tr>
<tr>
<td>Length of right l. [cm]</td>
<td>90.20</td>
<td>4.59</td>
<td>5.09</td>
<td>-0.286</td>
<td>-0.588</td>
<td>97.20</td>
<td>81.00</td>
</tr>
<tr>
<td>Length of left l. [cm]</td>
<td>89.75</td>
<td>4.34</td>
<td>4.83</td>
<td>-0.101</td>
<td>-0.347</td>
<td>97.20</td>
<td>81.50</td>
</tr>
<tr>
<td>Shoulder width [cm]</td>
<td>35.47</td>
<td>2.31</td>
<td>6.51</td>
<td>0.012</td>
<td>-1.185</td>
<td>39.00</td>
<td>31.50</td>
</tr>
<tr>
<td>Pelvis width [cm]</td>
<td>23.74</td>
<td>1.96</td>
<td>8.26</td>
<td>0.444</td>
<td>-0.141</td>
<td>28.00</td>
<td>20.50</td>
</tr>
<tr>
<td>Foot length [cm]</td>
<td>23.35</td>
<td>1.07</td>
<td>4.59</td>
<td>0.261</td>
<td>-0.831</td>
<td>25.50</td>
<td>22.00</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>19.01</td>
<td>2.40</td>
<td>12.63</td>
<td>1.096</td>
<td>1.664</td>
<td>25.25</td>
<td>15.34</td>
</tr>
</tbody>
</table>

All anthropometric data from the first and second measurement are shown in Figure 1, where we can clearly see an increase in all factors, which is normal for adolescent girls. The highest growth was in height, weight and length of the lower limbs, and the lowest – in the width of the pelvis, foot length and body mass index.
The empirical value of Student’s T-test exceeded the table-identified critical levels (Table 4). An additional circumstance is the fact that the guaranteed probability $P_t[\%]$ exceeded the critical (95%) value. Thus, with confidence, we should reject the null hypothesis and accept the alternative for the presence of a significant increase in data from the test sample, relating to the growth in the anthropometric variables. The data from the initial and final measurement of the anthropometric indicators are presented in Table 4, as well as the absolute value of the increment and its percentage equivalent. For clarity of the same line, the calculated Student’s T-distribution and the guarantee probability $P_t$ as shown.

### Table 4. Comparative analysis of the anthropometric variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>I meas.</th>
<th>II meas.</th>
<th>$d$</th>
<th>$d[%]$</th>
<th>$t$</th>
<th>$P_t[%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height [cm]</td>
<td>147.23</td>
<td>155.66</td>
<td>8.43</td>
<td>5.73</td>
<td>-10.35</td>
<td>100</td>
</tr>
<tr>
<td>Body weight [kg]</td>
<td>37.38</td>
<td>46.26</td>
<td>8.88</td>
<td>23.76</td>
<td>-9.53</td>
<td>100</td>
</tr>
<tr>
<td>Chest vol. [cm]</td>
<td>64.69</td>
<td>69.44</td>
<td>4.75</td>
<td>7.34</td>
<td>-9.91</td>
<td>100</td>
</tr>
<tr>
<td>Length right leg [cm]</td>
<td>85.01</td>
<td>90.20</td>
<td>5.19</td>
<td>6.11</td>
<td>-7.55</td>
<td>100</td>
</tr>
<tr>
<td>Length left leg [cm]</td>
<td>85.12</td>
<td>89.75</td>
<td>4.63</td>
<td>5.44</td>
<td>-6.83</td>
<td>100</td>
</tr>
<tr>
<td>Shoulder width [cm]</td>
<td>32.94</td>
<td>35.47</td>
<td>2.53</td>
<td>7.68</td>
<td>-7.55</td>
<td>100</td>
</tr>
<tr>
<td>Pelvis width [cm]</td>
<td>22.65</td>
<td>23.74</td>
<td>1.09</td>
<td>4.81</td>
<td>-4.05</td>
<td>99.99</td>
</tr>
<tr>
<td>Foot length [cm]</td>
<td>22.50</td>
<td>23.35</td>
<td>0.85</td>
<td>3.78</td>
<td>-5.36</td>
<td>99.99</td>
</tr>
<tr>
<td>BMI [kg/m$^2$]</td>
<td>17.17</td>
<td>19.01</td>
<td>1.84</td>
<td>10.72</td>
<td>-5.92</td>
<td>100</td>
</tr>
</tbody>
</table>

The movements of the figure skating athletes are spatial and are performed in two-support and one-support skating, as well as non-support (when performing jumps) and depend on both the dynamic parameters of the movement and the anthropometric parameters of the athlete (Vinogradova, 2013). In forecasting and orientation, it is necessary to understand the requirements of a sport to the quality characteristics of the athlete and how to change the indicators and proportions of body height and body weight, as well as physical qualities under the influence of growth and training. According to several authors – M. Matte, V. M. Zatsiorski and L. N. Sergienko, the most conservative are the peculiarities of the physique and speed-power qualities. The practice of figure skating suggests that among many dynamic and anthropometric
parameters that affect the angular velocity $\omega$ in arc gliding, the most significant are the grouping of the skater by retracting the arms and legs to the body. Research conducted by V. Vinogradova shows that maintaining balanced skating is better for skaters with a conical body shape. To create the initial rotation in the jumps, the cylindrical shape of the body is preferable. In the cylindrical shape of the body, the angular velocity $\omega$ of the equilibrium sliding of the skater is higher. The conversion of this speed into a rotational speed when flying around its longitudinal axis increases the rotations of the jump.

The jumps in figure skating are an integral part of motor activity. One of the conditions for their good execution are great height and length. Criteria for this are speed-power qualities, the coordination capabilities and sustainability of the vestibular system. A study of differential development of speed-power capability, regarding takeoff found that among girls and junior girls the highest rate of development was observed at the ages between 10 and 14 years old (Volkov, 1981; Goncharov, 1952; Grodzitska, 1983, etc.). Several studies show that despite jumping being an innate ability of humans, by applying effective exercises one can significantly increase the level of speed-power readiness of the athletes (Vershoshanskiy, 2013). In biomechanical aspects, jumps represent an upward movement of the body relative to the support surface by means of the lower extremities followed by flight with rotation and landing.

According to biomechanics this movement is realized by the formula $h_{\text{max}} = V_{\text{max}}^2 / 2g$ where $h_{\text{max}}$ is the height of the jump, $V_{\text{max}}$ is the maximum speed of the takeoff from the base, $t_{\text{takeoff}}$ is the time that takes place through the bounce by the leg in concentric action of the extensor of the feet and also according to the law on the impulse of power

$$F_{\text{max}} \cdot t_{\text{takeoff}} = m \cdot V_{\text{max}} \cdot t_{\text{takeoff}} \cdot \frac{m \cdot V_{\text{max}}}{F_{\text{max}}}.$$  

If the athlete acquires linear speed by acceleration, in the event of a sudden stop it causes impact action and resistance from the base. The impact counteraction causes acceleration due to the reaction of the base. In the interaction, the law of conservation of momentum $m \cdot V_1 = m \cdot V_2$ applies. The weight of the athlete is marked with $m$. Thus, if there is no deformation of the body and the base, the sliding speeds horizontally and the rebound vertically $V_1 = V_2$. The abrupt stop reduces the speed $V_1$ to 0 and if the amortization time $t_{\text{am}}$ is small, acceleration occurs according to the formula $a_{\text{am}} = V_1 / t_{\text{am}}$ and $V_2 = a_{\text{takeoff}} \cdot t_{\text{takeoff}}$.

The inertia when stopping causes a reaction of the support and a deviation in the upward direction.

$$V_{\text{max}} = F_{\text{max}} / m; F_{\text{max}} = m \cdot V_{\text{max}} / t_{\text{takeoff}}.$$  

Obviously, the maximum force occurs when the amortization time is short. Without force, there is no height $h_{\text{max}}$.

If the speed is 2 m/s, then the height becomes 0.2 meters, at 4 m/s – the height is 0.8 m, or it can be reached under ideal conditions. If the athlete adds extra strength during the push-up, it is added to the momentum of the reinforcement. Obviously, the damping and pushing times from the support must be as short as possible in the range of 0.1 or 0.2 seconds. If we imagine that we apply force for a long interval, we lose the effect of the athlete’s inertia. The force applied by the athlete must be for a short period of time to cause a cumulative effect on the inertia of movement. Weight $P = m \cdot g$; the indicator $g$ is the value of the ground acceleration equal to 9.8 m/s$^2$. Thus, it is possible to determine what linear speed the athlete must acquire to reach a given height to perform the rotation. In the case of a curvilinear movement of a skier or skater along a trajectory,
an inertial force of the centrifugal type arises, which gives great opportunities for changing the direction, because it facilitates the relief of skis or skates when reversing the direction of movement. The rotation is performed by itself. In the training of athletes, standards can be made defining mandatory requirements for speed or curvature of the sliding trajectory to achieve certain jumping indicators.

For the analyzes we consider the jump height \( h \), the maximum force \( F_{\text{max}} \) during the realized motor activity, the maximum speed \( V_{\text{max}} \), the takeoff time \( t_{\text{takeoff}} \) and the maximum acceleration \( a_{\text{max}} \).

The comparative analysis by Student’s T-test for dependent samples of indicators at different jumps in the first and second measurement are presented in Table 5.

Table 5. Comparative analysis of the biomechanics variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>I meas.</th>
<th>II meas.</th>
<th>( d )</th>
<th>( d ) [%]</th>
<th>( t )</th>
<th>Pt [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_{\text{SJ}} ) [m]</td>
<td>0.34</td>
<td>0.38</td>
<td>0.04</td>
<td>11.76</td>
<td>-3.59</td>
<td>99.75</td>
</tr>
<tr>
<td>( F_{\text{SJ max}} ) [kN]</td>
<td>0.75</td>
<td>1.47</td>
<td>0.73</td>
<td>97.33</td>
<td>-8.07</td>
<td>100.00</td>
</tr>
<tr>
<td>( V_{\text{SJ max}} ) [m/s]</td>
<td>2.11</td>
<td>2.59</td>
<td>0.48</td>
<td>22.75</td>
<td>-6.19</td>
<td>100.00</td>
</tr>
<tr>
<td>( t_{\text{SJ takeoff}} ) [s]</td>
<td>0.16</td>
<td>0.15</td>
<td>-0.02</td>
<td>-12.50</td>
<td>5.89</td>
<td>100.00</td>
</tr>
<tr>
<td>( a_{\text{SJ}} ) [m/s²]</td>
<td>13.00</td>
<td>17.75</td>
<td>4.75</td>
<td>36.54</td>
<td>-7.11</td>
<td>100.00</td>
</tr>
<tr>
<td>( h_{\text{CMJ}} ) [m]</td>
<td>0.37</td>
<td>0.39</td>
<td>0.02</td>
<td>5.41</td>
<td>-2.22</td>
<td>95.88</td>
</tr>
<tr>
<td>( F_{\text{CMJ max}} ) [kN]</td>
<td>0.72</td>
<td>1.40</td>
<td>0.68</td>
<td>94.44</td>
<td>-6.04</td>
<td>100.00</td>
</tr>
<tr>
<td>( V_{\text{CMJ max}} ) [m/s]</td>
<td>2.12</td>
<td>2.59</td>
<td>0.47</td>
<td>22.17</td>
<td>-5.45</td>
<td>99.99</td>
</tr>
<tr>
<td>( t_{\text{CMJ takeoff}} ) [s]</td>
<td>0.17</td>
<td>0.15</td>
<td>-0.02</td>
<td>-11.76</td>
<td>5.02</td>
<td>99.99</td>
</tr>
<tr>
<td>( a_{\text{CMJ}} ) [m/s²]</td>
<td>12.43</td>
<td>17.51</td>
<td>5.08</td>
<td>40.87</td>
<td>-6.19</td>
<td>100.00</td>
</tr>
<tr>
<td>( h_{\text{CMJA}} ) [m]</td>
<td>0.42</td>
<td>0.49</td>
<td>0.06</td>
<td>14.29</td>
<td>-4.70</td>
<td>99.98</td>
</tr>
<tr>
<td>( F_{\text{CMJA max}} ) [kN]</td>
<td>1.18</td>
<td>2.12</td>
<td>0.94</td>
<td>79.66</td>
<td>-4.19</td>
<td>99.93</td>
</tr>
<tr>
<td>( V_{\text{CMJA max}} ) [m/s]</td>
<td>2.40</td>
<td>2.96</td>
<td>0.56</td>
<td>23.33</td>
<td>-6.01</td>
<td>100.00</td>
</tr>
<tr>
<td>( t_{\text{CMJA takeoff}} ) [s]</td>
<td>0.18</td>
<td>0.17</td>
<td>-0.01</td>
<td>-5.56</td>
<td>2.18</td>
<td>95.55</td>
</tr>
<tr>
<td>( a_{\text{CMJA}} ) [m/s²]</td>
<td>13.64</td>
<td>18.16</td>
<td>4.52</td>
<td>33.14</td>
<td>-4.64</td>
<td>99.97</td>
</tr>
<tr>
<td>( h_{\text{DJ}} ) [m]</td>
<td>0.29</td>
<td>0.40</td>
<td>0.11</td>
<td>37.93</td>
<td>-3.91</td>
<td>99.88</td>
</tr>
<tr>
<td>( F_{\text{DJ max}} ) [kN]</td>
<td>0.62</td>
<td>1.51</td>
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<td>( a_{\text{DJ}} ) [m/s²]</td>
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<td>-5.51</td>
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There was an increase in all indicators, being especially significant at the maximum rebound force for all types of tested jumps, reaching 143.55% in the Drop Jump (Figure 2).
Figure 2. Growth of maximum force at different jumps

The increase in the reported rebound height in drop jump (Figure 3) was higher compared to other types of jumps – 37.93%, which is due to the specific abilities of skaters to perform jumps with good amortization when stepping into depth, followed by a rebound, of the ability to perform combinations of jumps, where it is important to maintain the momentum of the first jump.

Figure 3. The jump height

In second place for the height of the jump – 14.29% was a jump with the help of the hands, which is an indicator of good coordination of the competitors. The increase in maximum speed was also the highest in drop jump DJ – $VDJ_{max} = 59.41\%$ (Figure 4). There was a large increase in acceleration in all jumps and especially in the rebound after falling into depth – 83.22%. The repulsion time was negative.
Figure 4. The maximum speed

The correlation analysis in the two measurements (Tables 6 and 7) of the indicators from the studied sample includes analysis by Pearson’s multiple correlation. The indicators can be divided into two groups. One of them groups the results of anthropometric measurements, and the second forms the biomechanical variables, composed of kinematic and dynamic indicators. Intragroup correlation coefficients for anthropometric indicators in the first measurement are significant in nature – for the example height / weight (.758), height / chest circumference (.672), height / length of right leg (.896), height / length of left leg (.911), height / width of the shoulders (.880), height / width of the pelvis (.607), height / length of the foot (.917). The significant correlation coefficients of body weight to chest circumference (.848), weight / width of the shoulders (.756), weight / width of the pelvis (.693), weight / length of the foot (.679), body weight / BMI (.846). Intra-group correlations are also present in the biomechanical characteristics of kinematic and dynamic type – jump height / maximum force hSJ / FSJmax (.528), jump height / maximum speed hSJ / VSJmax (.741), jump height / time hSJ / tSJ (.534), maximum speed / acceleration VSJmax / aSJ (.826). The correlation coefficients quoted so far are positive and in nature express the proportional relationship between the indicators presented in the study. This circumstance means that as one of them grows, so will the other. Between time and acceleration tSJ / aSJ is obtained (-.688), a value which has a negative sign and certifies that an increase in one of them will lead to a decrease in the other. Intergroup significant correlation coefficients of interest for the study are height and force of the jump with the help of the arms depending on the width of the shoulders hCMJAmx (.638) and FCMJAmx (.582) and the length of the foot (.514 and .593), maximum speed depending from the length of the legs and the foot FCMJAmx (.594, .530 and .612). Dependencies in rebound of the drop jump have a negative sign to the width of the pelvis – hDJ – -.588, FDJ – -.513, VDJ – -.633. When performing 20 jumps, there is a dependence of the height of the bounce to the height \( r = .543 \), to the length of the legs \( r = .540 \) and
.513, to the width of the shoulders $r = .661$ and the length of the foot $r = .592$. The time depends on the same indicators, as the depen-

**Table 6. Correlations between anthropometric and biomechanics indicators – I test**

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<thead>
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<th></th>
<th>Body height</th>
<th>Body weight</th>
<th>Chest vol.</th>
<th>Length of left l.</th>
<th>Shoulder width</th>
<th>Pelvis width</th>
<th>Foot length</th>
<th>BMI</th>
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<th>F Jump max</th>
<th>Vmax</th>
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<th>a Jump</th>
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**Table 6. Correlations between anthropometric and biomechanics indicators – I test**
ANALYSIS OF THE DEPENDENCE BETWEEN ... Tatiana Yordanova

In the second measurement, Pearson’s intragroup coefficients for anthropometric indicators were again significant in nature but are slightly lower than in the first measurement. The intergroup significant correlation coefficients that are of interest for the study is the significant dependence of the maximum strength of all types of jumps on the growth of the athletes. There is a significant dependence of strength on weight and chest volume in all jumps except semi-squat takeoff. Interestingly, the height of all jumps depends on the width of the shoulders, the highest is the Pearson coefficient r = .644 and .663 in the takeoff without the help of the arms and in 20 consecutive jumps. The maximum force is significantly dependent on all anthropometric indicators. Only the width of the pelvis does not affect this indicator. Indicator of maximum speed when jumping with the arms and after rebounding from height to shoulder width, respectively r = .535 and .488.

**Table 7. Correlations between anthropometric and biomechanics indicators – II test**

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The analysis of the biomechanical characteristics of different types of jumping takeoff shows a significant increase in the maximum force, which allows to increase the height of the jumps. The increase in jump height in Drop Jump is the highest compared to other jumping indicators, which is probably due to the good amortization when stepping to a depth of 30 cm, followed by a rebound, and the ability to perform combinations of jumps while maintaining the inertia of the first jump. In second place is the increase in height when jumping with the help of the arms, which is an indicator of good coordination, while the increase in maximum speed is highest in rebounding with prior amortization.

The increase in body mass index is very low in the second measurement compared to all other anthropometric indicators, which
confirms the effect of training on body weight.

Significant intragroup dependences for the anthropometric and biomechanical indicators for all types of jumping takeoff were established and the decrease of the correlation coefficients was observed in the second measurement. At the same time, the maximum force in all types of jumps increases with increasing indicators of height, weight, length of the lower limbs, chest circumference, shoulder width, while the width of the pelvis does not affect the force of the takeoff. The height of the jump depends on the width of the shoulders. The dependence ranges from moderate $r = .497$ when jumping with the arms to significant $r = .664$ when jumping vertically with the hands on the hips. Pearson coefficients of intragroup biomechanical parameters range from significant force $r = .508$ to very strong $r = .911$ between height and maximum jumping force.

We can make some pedagogical recommendations. The increase in sports results in figure skating requires the use of progressive teaching technologies to improve the technique of complex multi-rotational jumps. First of all, this implies knowledge of theories, rules that help to properly understand the complex kinematic and dynamic characteristics of movements. Having the basics of biomechanical analysis, a complex movement can be broken down into a number of its components and thus to understand its structure, to see the errors, to outline the prospects for the development of movement techniques, to select and define a set of special exercises aimed at mastering the technique of motor action, and to choose appropriate training methods. In figure skaters' jumps, swinging movements contribute to the movement of the General center of gravity of the body in the direction of takeoff, improve the coordination of movements during repulsion, provide a stable movement of the axis of rotation in flight phase, and increase the aesthetic impression of the jump. The movement of the free limbs and the skater's body during the jump change the magnitude of the base reaction. They are effective only when there is coordination of flexion and extension of the pushing leg. The coordinated execution of swinging movements and extension of the repulsive leg, the effective interaction of the skate with the ice make it possible to perform the required number of revolutions in flight with a stable movement of the axis of rotation.

REFERENCES


мышечных сокращений при предельных напряжениях и ее возрастные изменения: Автореф. дисс. канд. пед. наук. Москва, 1952.


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SHORT-TERM TRAINING PROGRAM FOR THE PREPARATION PERIOD IN THE ENDURANCE DISCIPLINE OF EQUESTRIAN SPORT

Ruzha Nedkova-Ivanova, Yuri Valev
National Sports Academy “Vassil Levski”, Sofia, Bulgaria

ABSTRACT

The competitive pairs of horse and rider in the endurance discipline of equestrian sport in Bulgaria have ranked, in the past several years, amongst the elite contestants in Europe and the world, which has necessitated deeper studies in the areas of training methods and the ways of achieving high sport results. Therefore, this study is focused on 6 Bulgarian horses (Arabian horse and Shagya, Table 1) that are preparing for European and World championships. They were trained together under the same conditions (climate, time zone, terrain, speed) by riders with the necessary qualifications and experience. Seven training rides were performed, and the pulse was measured at the moment of the highest load, as it is the most indicative of the horse’s level of effort. By studying the pulse of horses during a training session, the research aimed to determine the efficacy of the short-term training program in the prep season. The results showed that 2 to 4 minutes after coming to a full stop, regardless of the terrain, speed (in this research between 5.2 km/h and 22.5 km/h) or distance travelled by the horses, their pulse varied between 36 and 99 bpm (beats per minute) and they improved their physical condition and increased their stamina without this leading to trauma or more serious injuries, which is a main priority in the equestrian sport and allows for the successful completion of every race. In the long run, such a training methodology will allow the horses to be trained and ready to race at any time. Monitoring the heart rate and keeping it within the studied limits showed that this was the optimal option for a training regime for the six examined horses. In the situation with the COVID-19 pandemic, this is a possible solution for maintaining athletic fitness in endurance horses.

Key words: horse, endurance, training, preparation period, pulse.

INTRODUCTION

The endurance event in equestrian sport is a challenge to the rider in terms of his capabilities to lead the horse in a precautious manner on the endurance track. The route is designed to test the stamina and fitness of the rider and the horse, respectively, against the marked tour, distance, terrain, climate and clock without compromising the well-being of the horse (FEI, 2020). Endurance sport’s highest concept is “fit to continue”. This term should have meaning for the endurance riders “that goes far beyond just the sense of the “race” itself” (Loving, 1997).

There are a lot of studies about the physiology of sport horses in competitions or in training in the different equestrian disciplines, including: racing (Vermeulen and Evans, 2006), trotters (Fortier et al., 2015), polo (Ferraz et al., 2010), endurance riding (Fraipont
et al., 2012) and western sports (Casella et al., 2015). Endurance riding is not an Olympic discipline, but currently the most popular in Bulgaria with the high achievements of the endurance competitors. The country has already high qualified riders for the highest-level endurance races – European and World Championships and the World Equestrian Games (Valev, 2020). The European Championships are held in even-numbered years, the World Championships in odd-numbered years, and the World Equestrian Games are held every 4 years (FEI, 2020). All championships in the endurance discipline are held at a distance of 160 km over one day and with an average speed of over 12 km/h for each loop of the competition. The loops are 6, divided into distances between 40 and 20 km (FEI, 2020). The races organized in this way allow couples competing in the endurance discipline to take part every year in competitions of the highest category, which require appropriate training, because such competitions are attended by elite horses and riders who have met the necessary qualifications and have shown the best achievements in current racing year or the previous one. Since the horse has a leading role in the horse-rider couple, this research was based on its functional indicators and its overall physical condition.

Endurance horses undergo severe stress during the course of a competitive ride. These horses are trained and conditioned to perform over long distances at moderate speeds. When conditioning a horse for long distance competitions, the training program must be designed and monitored to match the specific exercise type and intensity of competitive endurance riding (Linder et al., 2006).

To follow the progress of the endurance horse, it is important to check its ability to perform the required work regularly without physical or metabolic hazard. For this aim, riders and trainers in Endurance use cardio-tachometer or heart rate monitor to check the heart rate during and after a ride. This helps to understand how well horses cope with the exercise stress. Ideally, horses recover their pulse to less than 60-64 bpm within 5-10 minutes following an aerobic workout (Loving, 1997).

The relationship of the heart rate and the performance of the horse were described by Steel in the 1960’s (cited in Steward, 1981) and are still important makers for the fitness and health of the sports horse, especially in endurance. Only more recently have training programmes evolved to use more quantitative assessments of horses’ athletic improvement. Heart rate, oxygen consumption and lactate accumulation with exercise are quantitative factors that can evaluate progress (Persson 1983; Pringle et al. 1999). The running speed-heart rate relationship is easily measured and reproducible and can be applied under field conditions (Couroucé et al., 2000). On the other hand, heart rate can be influenced by external factors such as anxiety or excitement and can fluctuate significantly at lower working intensities. Even with its limitations, heart rate is still used extensively as a fitness indicator (Trilk et al., 2002). Oxygen consumption is a metabolic indicator of fitness and athletic improvement. Substrate utilisation and energy expenditure can be determined through measuring oxygen consumption (Seeherman and Morris, 1990), but it is generally available only for clinical trials and is impractical for field use (Trilk et al., 2002). Blood lactate measurements are also used regularly to assess the level of horse’s fitness and there is a lot of research, which shows the connection to the condition of the horse (Mohr et al., 1999). Taking blood from horses during training is also a complicated process demanding a veterinarian and more preparation.

Bulgaria has twice successfully ranked...
among the best teams in the world and Europe so there is a resource of horses and riders at the highest level. This study was based on the heart rate of Bulgarian elite horses (Arabian horse and Shagya, Table 1) as one of the main information indicators for the training of the horse, along with blood lactate (Castejon-Riber et al., 2017). The presented training program and its results will enable all elite athletes and coaches in this discipline to compare and upgrade their work in order to improve sports results.

**PURPOSE OF THE STUDY**

This study aims to provide a developed short-term training program for elite horses in the discipline of endurance in equestrian sports, which refers to the preparatory (initial) period of training preceding the racing season. This program aims to gradually improve sports conditions of the horses, preparing them for loading during the race at distances of 120 km to 160 km per day at speeds above 12 km/h for each stage of the race, protecting them from traumas, injuries that may be the result of both insufficient training or overtraining.

The training is fully adapted to the age of the horses, their racing level so far, as well as their physical condition at any time during the training. The highest principle in equestrian sport is the preservation of the welfare of horses (Robert, 2002), whether in training, competition or during rest, so the applied program should be guided by it.

The specified short-term training program will implement a study that has not yet been conducted in Bulgaria on a similar scale. The results will give information about the club for which the six horses compete and whether their training methodology is correct or needs improvements and changes. Bulgarian Endurance riders are quite successful nationally and internationally, but these achievements are not based on a clearly elaborated methodology that is accessible to everyone, so such a study allows for a wider range of stakeholders to learn about scientifically developed methods for training horses for endurance discipline.

**MAIN HYPOTHESIS**

The short-term training program for elite horses breed types (Arabian horse and Shagya, Table 1) in the endurance discipline should be fully adapted to their physical condition. We believe that a training in which horses are ridden the longest time (over 70% of training) at a heart rate between 64 and 150 bpm and after stopping for 2 to 4 minutes their heart rate is between 36 and 99 bpm will improve their racing capabilities without causing trauma or more serious injuries and will fully prepare them for top-ranked races.

**METHODS**

The research was done with 6 horse-rider racing pairs and presents the results from the measurement of the heart rate of the horses as a key indicator of the horse training in seven training rides with different loads. The heart rate measurements were made during or at the end of the training, which took place on different terrain – flat, down and uphils, field and mountains, and were of different duration – between 1 and 2 hours, and speed between 5.2 km/h and 22.5 km/h (Figure 2). The racing couples performed the training program as set in Tabl. 3 - week model for two and a half months. Pulse was measured 42 times in 7 rides of 6 horses. All six pairs are elite competitors successfully ranked at international competitions with the rank of CEI 2* (120-139 km/day) and CEI 3* (140-160 km/day) and preparing to participate in the World Championship (160 km/day, 3* Championship) in the discipline endurance. The horses are aged between 9 and 13 years, and the competitors are aged between 27 and 54 years.
According to the international regulations of FEI (International Equestrian Federation) age condition gives them the right to participate in competitions, men’s category CEI 2*, CEI 3* and Championship, after successfully passing all mandatory qualifications.

SPSS statistics software and polarflow application were used in the processing of the results.

**Subjects**

The participants in the study – horses and riders and their specifics are shown in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Table 1. Breed, age and gender of horses participating in the study</th>
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<tbody>
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<td>Horse</td>
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<table>
<thead>
<tr>
<th>Table 2. Age, gender and level of completed competitions of the riders of six horses included in the experiment.</th>
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<tbody>
<tr>
<td>Rider</td>
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</table>

All the 6 riders had successfully completed races at a distance of 120 km. Five of them had successfully completed competitions at 160 km. The riders were prepared for competitions at a distance of 120 and 160 km and met the training requirements and qualifications of the six horses in the experiment.

**Materials**

A Polar Ignite watch, a Polar belt heart rate monitor, a Polar Equine Healthcheck, a handheld heart rate monitor, the Polar Flow application and some information from www.flow.polar.com, were used for conducting the study as usually used in other studies (Lindner et al., 2020). Polar belt heart rate monitor and Polar Equine Healthcheck were attached to the thorax of the horse as described in the manufacturer’s instructions. Some gel was used for full contact between skin and device.

**Duration of the study**

The study started on January 1, 2020 and ended on March 13, 2020 along the following monthly plan (mesocycle) under the supervision of the coach and the team’s veterinarian:

- LSD (Long Slow Distance) – 3-4 times monthly;
- Basic training – 6-8 times monthly;
- Manege training – 3-5 times monthly;
- Conditioning training – 4-6 times monthly;
- Full rest in the paddock – 4-8 days monthly;
EXPLANATION OF TERMS:
1. Basic training – this is the degree of work with the horse that does not stress it. It helps building its physical condition properly.
2. Manege training - these are the days for work when the horse rests from stress. The workout can include 20 minutes work with a horse walker - walking and trotting or manege work from the ground and on the saddle with certain exercises.
3. Conditionning training – a work with the horse, which allows it to become strong and tough enough to participate in endurance competitions without danger for its health.
4. Heavy loading/canter - this is a load for the horse, to which it is generally not accustomed and requires more energy. It is typical for this type of training that the horse’s heart rate is higher than the usual within 20 minutes. This means that the horse is loaded to a sufficiently high degree and reaches a level of stress.
5. Rest day - normally this is the day after a heavy load training, and sometimes these days are 2 or more depending on the trainer’s judgement.

The weekly training program (microcycle) is presented in Table 3. (Valev, Nedkova-Ivanova, 2018).

Table 3. Weekly training program

<table>
<thead>
<tr>
<th>Day of the week</th>
<th>Training program</th>
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<tbody>
<tr>
<td>Monday</td>
<td>Rest</td>
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<tr>
<td>Tuesday</td>
<td>Basic training with up-riding (1-2 h)</td>
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<tr>
<td>Wednesday</td>
<td>Manege training</td>
</tr>
<tr>
<td>Thirsday</td>
<td>Conditioning training (1-2 h)</td>
</tr>
<tr>
<td>Friday</td>
<td>Rest</td>
</tr>
<tr>
<td>Saturday</td>
<td>Cross country basic training (1-3 h)</td>
</tr>
<tr>
<td>Sunday</td>
<td>(canter)/conditioning training</td>
</tr>
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</table>

Table 4. Pulse rates during different gait

<table>
<thead>
<tr>
<th>Movement</th>
<th>Pulse (beats/minute)</th>
<th>Loading level</th>
<th>Energetic system</th>
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</thead>
<tbody>
<tr>
<td>Standing</td>
<td>25-60</td>
<td>very low</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Walk</td>
<td>50-90</td>
<td>very low</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Trot</td>
<td>80-150</td>
<td>low</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Canter</td>
<td>120-160</td>
<td>moderate</td>
<td>Mostly Aerobic</td>
</tr>
<tr>
<td>Gallop</td>
<td>150-200</td>
<td>high</td>
<td>Mixed Aerobic and anaerobic</td>
</tr>
<tr>
<td>Carriere</td>
<td>200-230</td>
<td>very high</td>
<td>Highly anaerobic, partly aerobic</td>
</tr>
</tbody>
</table>

It is important for endurance horses to be ridden at such a pace that they do not reach a heart rate higher than 100-150 bpm (Table 4). Under heavy load/canter, the pulse can reach 220 bpm depending on the type of terrain and speed, but this state should last a maximum of 20 minutes (Evans, 2000). Even though endurance riding is classified as a prolonged aerobic exercise (Siqueira et al., 2014), the high oxygen demands over a longer period of time result in an increased reactive oxygen species (ROS) formed by 1 to 2% of the oxygen that is not completely reduced into carbon dioxide and water (Sjodin et al., 1990).
RESULTS AND ANALYSIS

The obtained results showed that these six horses’s pulse frequencies varied between 47 and 202 bpm, and their average frequency was 103 bpm, which is shown in Figure 1. The condition to not be ridden when the horse’s pulse rate was above 200 bpm was respected for not more than 20 minutes. The data showed that horses were ridden with a heart rate between 171 and 202 bpm within 4 minutes and 39 seconds. The speed of the horses in the training seasons was between 5.2 km/h and 22.5 km/h, shown in Figure 2.

![Figure 1. Typical heart rate distribution during endurance horse training (the graph was taken from the Polar Flow application, which was prepared from Polar Ignite watch data after training).](image)

Despite the differences in training grounds and distances, pulse indicators vary within the limits of the permissible conditioning load during the preparation period, namely between 36 and 99 bpm, measured from 2 to 4 minutes, with speed limits from 5.2 km/h to maximum 22.5 km/h (Figure 2).

After all heart rate measurements, the follo-
wing summaries and conclusions can be made, (see Table 5 and Table 6): Horses maintained a relatively constant heart rate during their seven training sessions. The coefficient of variation belongs to the interval 20 - 30% \( V \% \in [20 - 30] \); The horses’ heart rate varied between 36 and 99 beats per minute, which shows that the training methodology was applied correctly and gave its positive results on the physical condition of the horses.

**Table 5. Minimum and maximum heart rate of the six horses participating in the seven training rides.**

<table>
<thead>
<tr>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71.71</td>
<td>15.607</td>
<td>5.899</td>
<td>57.28</td>
<td>86.15</td>
<td>44</td>
</tr>
<tr>
<td>2</td>
<td>75.00</td>
<td>21.894</td>
<td>8.275</td>
<td>54.75</td>
<td>95.25</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>63.14</td>
<td>16.517</td>
<td>6.243</td>
<td>47.87</td>
<td>78.42</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>67.00</td>
<td>17.786</td>
<td>6.722</td>
<td>50.55</td>
<td>83.45</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>70.14</td>
<td>19.386</td>
<td>7.327</td>
<td>52.21</td>
<td>88.07</td>
<td>39</td>
</tr>
<tr>
<td>6</td>
<td>66.29</td>
<td>17.604</td>
<td>6.654</td>
<td>50.00</td>
<td>82.57</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>68.88</td>
<td>17.543</td>
<td>2.707</td>
<td>63.41</td>
<td>74.35</td>
</tr>
</tbody>
</table>

* N = number of rides

**Table 6. Pulse rate variation factor for the seven rides.**

<table>
<thead>
<tr>
<th>Number</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Variance coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71.71</td>
<td>15.607</td>
<td>21.76%</td>
</tr>
<tr>
<td>2</td>
<td>75.00</td>
<td>21.894</td>
<td>29.19%</td>
</tr>
<tr>
<td>3</td>
<td>63.14</td>
<td>16.517</td>
<td>26.16%</td>
</tr>
<tr>
<td>4</td>
<td>67.00</td>
<td>17.786</td>
<td>26.55%</td>
</tr>
<tr>
<td>5</td>
<td>70.14</td>
<td>19.386</td>
<td>27.64%</td>
</tr>
<tr>
<td>6</td>
<td>66.29</td>
<td>17.604</td>
<td>26.56%</td>
</tr>
<tr>
<td>7</td>
<td>68.88</td>
<td>17.543</td>
<td>25.47%</td>
</tr>
</tbody>
</table>

It can be seen that at significance level \( \alpha = .05 \) the result from the test for homogeneity of scattering (Levene Test) shows that there was no significant difference between scattering in heart rate values in the studied horses (Sig = .904 > .05). The conclusion is confirmed by the results from the analysis of the variance (Table 8). With a 95% guarantee probability (\( \alpha = .05 \)) we can say that the pulse rate of the studied horses was constant (Sig = .859 > .05). Perceiving the pulse rate as a measure of training of the studied horses, the conclusion is that they had the same degree of training and preparation.

**Table 7. Levene test for the difference between scattering in heart rate values.**

<table>
<thead>
<tr>
<th>Levene Statistic</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.310</td>
<td>5</td>
<td>36</td>
<td>.904</td>
</tr>
</tbody>
</table>

**Table 8. Anova test for the constant pulse of the six horses.**

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>631.833</td>
<td>5</td>
<td>126.367</td>
<td>.380</td>
</tr>
<tr>
<td>Within Groups</td>
<td>11986.571</td>
<td>36</td>
<td>332.960</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12618.405</td>
<td>41</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

75
In table 9 we can see the six horses’ heart rates measured during their seven training rides, clearly showing that they varied between min 36 bpm and max 99 bpm.

**Table 9. Difference between the minimum and maximum heart rate of the six horses and the average heart rate.**

<table>
<thead>
<tr>
<th>Horse pulse</th>
<th>N</th>
<th>Range Statistic</th>
<th>Minimum Statistic</th>
<th>Maximum Statistic</th>
<th>Mean Statistic</th>
<th>Std. Deviation Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>44</td>
<td>44</td>
<td>88</td>
<td>71.71</td>
<td>15.607</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>59</td>
<td>40</td>
<td>99</td>
<td>75.00</td>
<td>21.894</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>51</td>
<td>36</td>
<td>87</td>
<td>63.14</td>
<td>16.517</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>48</td>
<td>41</td>
<td>89</td>
<td>67.00</td>
<td>17.786</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>56</td>
<td>39</td>
<td>95</td>
<td>70.14</td>
<td>19.386</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>51</td>
<td>38</td>
<td>89</td>
<td>66.29</td>
<td>17.604</td>
</tr>
</tbody>
</table>

*N = number of rides

According to table 10 and the Kolmogorov-Smirnoff test, the heart rate values for the six horses were normally distributed, at a significance level α = .05 (Sig = .978 > .05).

**Table 10. Distribution of values**

<table>
<thead>
<tr>
<th>Horse 1 pulse</th>
<th>Horse 2 pulse</th>
<th>Horse 3 pulse</th>
<th>Horse 4 pulse</th>
<th>Horse 5 pulse</th>
<th>Horse 6 pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Normal Parameters^a,b</td>
<td>Mean</td>
<td>71.71</td>
<td>75.00</td>
<td>63.14</td>
<td>67.00</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td>Absolute</td>
<td>.180</td>
<td>.162</td>
<td>.187</td>
<td>.160</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>.148</td>
<td>.136</td>
<td>.153</td>
<td>.160</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>-.180</td>
<td>-.162</td>
<td>-.187</td>
<td>-.143</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>.475</td>
<td>.428</td>
<td>.494</td>
<td>.424</td>
<td>.463</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.978</td>
<td>.993</td>
<td>.968</td>
<td>.994</td>
<td>.983</td>
</tr>
</tbody>
</table>

The measurements showed that the average heart rate of the examined horses ranged from 63.14 to 75 beats per minute. The minimum measured heart rate for horse 3 was 36 bpm, and the maximum for horse 2 - 99 bpm.

The effects of exercise speed and duration on heart rate recovery were previously described (Hall et al., 1976). In this research horses were ridden for training and with speed between 5.2 km/h and 22.5 km/h. This was the limit, set by the trainer and veterinarian, so the horses were not trained under stress for a long time. In the long term, the body systems of the horse adapt to the stress of exercise. This helps for producing more energy and for strengthening the supporting structures. Too much stress between workouts leads to overloading injuries (Clayton, Science, 1992).

There are a lot of studies showing the relationship between heartrate and physical condition of sports horses. Few are the studies especially carried out with endurance sport horses, which are based more on competition level (Bennet, Parkin, 2018), than on training, so more research had to be done in this direction. It was important to design a methodology of training precisely oriented to Bulgarian endurance horses’ conditions. Another study followed a standardized stepwise exercise test for endurance horses and the connection...
to heart rate, but there were different types of horses and at a different level (Sloet van Ol-druitenborgh-Oosterbaan et al., 1987). Such studies were carried out in the 80’s (Asheim et al., 1970), the technical materials for measuring the heart rate has changed, the speeds of the horses have changed, FEI rules have changed many times (https://inside.fei.org/node/3835/), so the information is not as relevant as desired any more. New surveys about heart rate of high-level endurance horses in training are needed. There are not such studies in Bulgaria or such methodologies of training. Therefore, this study is of great importance for development of endurance riding discipline in the country.

**Limitations and future research directions**

As the implementation of the study coincided with the beginning of the COVID-19 pandemic in Bulgaria, the period of preparation for upcoming competitions was extended indefinitely. The horses were trained according to the method described above; only the heavy load/canter was reduced and replaced with conditioning training (with a horse walker on walking and trotting programs) because training was prohibited. In this program the horses remained healthy, motivated, in very good shape and with a desire to work, which was evident in the resumption of training on May 4, 2020. When working in this direction at the start of the racing season, these 6 horses could acquire cantering and could be in top form on the day of the race two weeks before announced competition. Given the unexpected situation, the fact that the horses kept their heart rate constant and were in good general physical condition, gives the reason to believe that such a developed methodology is not only suitable for short-term training program, but also at such moments that require a radical change in preparation plans and strategies.

In order to implement the presented methodology among a wider range of stakeholders and to improve the shown results this test should be supplemented and continued with tests during the active racing period and immediately before the CEI 2* and CEI 3* races, measuring the heart rate during and immediately after a longer canter between hour and hour and half without a break. Some seminars and online trainings can be organized, paying special attention to the topic of training horses in Endurance discipline and presenting the final results from this experiment. The promotion of using technical equipment and the constant monitoring of the horses’ heart rate during training are a main helper in detecting problems related to the physical condition of the horses.

**CONCLUSION**

In this study, it was concluded that by regularly monitoring the heart rate of horses, it can be judged whether these horses feel equally well and are equally trained in the short-term training program. The results of the measurements showed that the six horses accepted the load under which they are subjected positively, and their heart rate remained within acceptable limits.

**REFERENCES**


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E-mail: ruja_83@yahoo.com
STUDIES ON A PARADOX IN THE WORK OF THE UPPER LIMBS IN ISOMETRIC STRETCHING

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²National Sports Academy “Vassil Levski”, Sofia, Bulgaria

ABSTRACT

Stretching is a common activity used by athletes, elderly, rehabilitation patients, people involved in fitness programs and many others. In isometric stretching an elongation in the linear dimensions of the kinematic chain of the upper limbs is observed. The aim of this study is to show the importance of intra-articular processes as response of isometric stretching force, as well as to mark the basic factors which define the joint answer to stretching, describing experimental data, relative to these factors. The present work has a programmatic character in terms of the directions in which the answer to the laid aims should be sought. The main focus is on the biomechanical processes in the joints involved in the obtained kinematic chain extension.

Key words: isometric stretching, joint, intra-articular processes.

INTRODUCTION

Stretching is a common activity used by athletes, elderly, rehabilitation patients, people involved in fitness programs and many others (Page, 2012). Weerapong, Hume, & Kolt (2004), define stretching as “movement applied by an external and/or internal force in order to increase muscle flexibility and/or joint range of motion”.

Static stretching is the most widely used technique by athletes due to its simplicity and ease of execution. It has been found that static stretching affects both the mechanical and neurological properties of the muscle-tendon block, leading to increased musculoskeletal flexibility (Weerapong, Hume & Kolt, 2004).

Isometric stretching is a type of static stretching (in the sense that it does not use motion) which involves the resistance of muscle groups through isometric contractions (tensing) of the stretched muscles (Appelton, 2009). Due to the fact that in this type of stretching the muscles work in an isometric mode, the developed muscle forces will undoubtedly affect the joints around which the respective muscles are located. These muscular forces are applied to the bones at the points of attachment of the tendons to the bone. When we have active isometric stretching of more muscle groups passing over a certain joint, the muscular forces obtained during this stretching will cause processes inside the joint itself.

The effects of stretching on muscle properties are well studied and depend on various factors, such as the stretching techniques used, the stretching time, the length of stay, the rest time and the time difference between the intervention and the measurement, and
many others. Most publications have studied the effects of static stretching on the passive properties of the muscle-tendon block (Magnusson et al., 1996a, 1996b), (McNair et al., 2000), (Magnusson et al., 1995), (Magnusson et al., 2000). In a series of studies by Magnusson et al., (1996a, 1996b, 1996c), static stretching for 90 seconds with five repetitions reduced muscle resistance, measured by passive stiffness, maximum torque, and stress relaxation. Another team of researchers concluded that changes in the viscoelastic properties of the muscle-tendon block depend more on the duration of stretching than on the number of stretches (Kubo, Kanehisa, Fukunaga, 2001).

Prolongation of static stretching (from five to ten minutes) has been shown to reduce tendon stiffness (Kubo, Kanehisa, Fukunaga, 2001), (Kubo, Kanehisa, Fukunaga, 2002). The reduction in stiffness may be due to a change in the arrangement of the collagen fibers in the tendon (Kubo, Kanehisa, Fukunaga, 2001).

The combination of stretching exercises with other therapeutic techniques, such as warm-up (Magnusson et al., 2000) (Stojanović et al., 2017), heat/cold (Henricson, 1984), (Taylor, Waring, Brashear, 1995), (Burkeet al., 2001) and massage (Weerapong, Hume & Kolt, 2004), (Rodenburg et al., 1994), have been used to improve practical results of stretching.

Warming up causes an increase in muscle temperature, which helps to improve tissue flexibility. In a study by Magnusson et al., (2000), warming up (jogging) for 10 minutes (performed at 70% increase in oxygen flow), leads to increased muscle temperature by 3%.

Massage, stretching and warming up are often used in sports practice to prevent muscle injuries. Rodenburg et al., (1994) reported that combining these techniques may reduce some of the negative effects of eccentric exercise-induced soreness. Applying warm-up procedure aims to reduce the viscosity of muscle tissue and stretching aims to reduce passive tension. The results show that the combination of these techniques does not affect the treated areas more than any individually performed technique per se. Other studies have reported that warm up effectively reduces muscle sensitivity and loss of functionality (Weerapong, Hume & Kolt, 2004), (Nosaka, Clarkson, 1997), massage is effective in reducing the sensation of pain (Weerapong, Hume & Kolt, 2004), (Bale, 1991), (Tiidus, Shoemaker, 1995), while stretching has no effect. (Johansson et al., 1999). However, the influence of a combination of stretching exercises with other therapeutic techniques (warm-up, heat/cold, massage) on joint response and joint biomechanical properties is not studied in detail yet.

The results of Maeda et al. show that static stretching for 2 minutes a day significantly increases the range of motion of the joint. There has also been a significant reduction in muscle stiffness (Maeda et al., 2017). Several teams noted an individual response of the body during stretching exercises (Curry et al., 2009), (Dalrymple, 2010). Therefore, stretching programs can and should be individualized in view of different factors, goals and individual characteristics of the patient or athlete (Weerapong, Hume & Kolt, 2004).

A review by Harvey et al. shows an assessment of the impact of different types of stretching for the prevention and treatment of contractures (contracture is a permanent shortening or stiffening of muscles, tendons, ligaments, skin or connective tissue, which leads to reduced range of motion). The same team reported challenging results on the lack of clinical effect of stretching on joint mobility. These results contradict the fundamental
acceptance in physiotherapy that stretching is effective in treating and preventing contrac-
tures (Harvey et al., 2017).

The preceding analysis shows the effects of stretching on the muscle-tendon block. However, the influence of stretching on the function and processes inside the joints is insufficiently studied. In other words, what happens inside the joint in isometric stretching, as far as we know, has not been studied and clarified.

Over 70% of the problems that occur in the human musculoskeletal system are of joint origin, and in some specific categories of work, including sports, it is higher. In this regard, the study of intra-articular processes and the effects of the reaction to the load on the joints could be the basis of approaches to:
- finding optimal motor tasks related to joint training;
- joint rehabilitation;
- synthesis of rehabilitation and sports simulators;
- synthesis of artificial joints, applicable both in medical practice and in technical devices supporting human movements (exo-skeletons, active orthoses, etc.)

The creation of an appropriate motor program for studying the intra-articular processes and movements depending on the purpose of the work with the respective joint is a complex interdisciplinary problem.

The aim of this study is to show the importance of intra-articular processes as response of isometric stretching force loading, as well to mark the basic factors which define the joint answer to stretching, describing experimental data, relative to these factors. The present work has a programmatic character in terms of the directions in which the answer to the laid aims should be sought. The main focus is on the study of the reasons for elongated kinematic chain of stretched upper limbs, involved in presented experimental model.

MATERIALS AND METHODS

In musculoskeletal biomechanics, the model considering the interaction of skeletal and muscular elements is based on analogies with the interaction of units and forces in lever mechanisms (Hall, 2007). According to this model, bones are the units and muscles are the engines that drive them. The magnitudes of the forces of interaction between the units of the mechanism (i.e., load in the joints) and the magnitudes of the muscular forces of the overall interaction with the internal and external environment are a consequence of the geometric proportions of the connections between skeletal and muscular elements. The idea for this is shown in Figure 1 (Hall, 2007). In general, this model presents the joints of the limbs, as mechanisms with alternative bilateral muscle drive (Figure 2), and the limbs themselves as open lever mechanisms. With its help the force-speed characteristics of the limbs are well described and explained (Miladinov, Velin, 2018; Peev, Gadev, 2018), but some effects of the musculoskeletal interaction cannot be explained, such as the lengthening of the kinematic chain of the upper limbs when their muscles are tensed. This effect will be described below and is a “paradox”.

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Figure 1. Interaction of skeletal and muscular elements is based on analogies with the interaction of units and forces in lever mechanisms.

The “paradox” extension, experiments.

Figure 2. The limbs as lever mechanisms.

Figure 3 shows a diagram of an experimental setup using which the following experiment was performed:

- The participant lies on his back on a hard surface so that full contact of the shoulder girdle with it need to be obtained.
- Stretches his arms out to the side (Figure 3). The endpoints (A - lateralis dexter digitus medius and B-lateralis sinister digitus medius) are in contact with the sensing axes ofmicrometers (linear displacement reading accuracy 0.01 mm).

Figure 3. Measurement scheme.

- In this position, the measuring instruments are reset by fixing the distance between their contact points A and B.
- In the next stage, the participant performs an isometric contraction of the muscles (which he can control voluntarily) included in the formed kinematic circuit between the two measuring devices (points A and B). It should be noted here that for different individuals, although isometric, the contraction of these muscles is not the same, both in the characteristics of the contractile act of each of the participating muscles and in their nomenclature, as the total effect of this multiple muscle contractions
depends on the individual characteristics of the individual participants in the experiment.

• Despite these differences, as a result of the performed motor task, the following common effect is observed for all participants in the experiment: the formed kinematic chain between points A and B increases its length. According to the existing in the literature kinematic models of the bone and joint apparatus of the shoulder girdle and the forelimbs, it is built only of rotational connections. With this structure and the maximum extension of the arms before stretching, which is carried out in the study, there should be no increase in its linear dimensions. While in fact such an increase is registered, which is the paradox in its behavior.

RESULTS

The effect described above was observed in an experiment with 30 participants, athletes, in the age group 13-17 years, 18 boys and 12 girls. In Table 1 and Table 2 (Table 1 - girls and Table 2 - boys) in the first column is given the number of the participant, and in the next two columns (respectively Right and Left) are given the measured readings of the micrometers in millimeters. The increase in the length of the kinematic circuit is the sum of the two readings (Right + Left). It should be noted here that this effect is also observed in other stretching exercises performed both by individual joints and by connected bone chains. Naturally, the question arises as to the reasons for the elongation of the kinematic chain (in the case of the upper limbs), which we have described as a paradox.

The answers to this question are related to the experimental study of intra-articular movements, processes and effects of force loading of the joints.

Table 1. Kinematic chain elongation in mm, left and right micrometric devices, girls.

<table>
<thead>
<tr>
<th>Girls</th>
<th>Left, mm</th>
<th>Right, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>18.00</td>
<td>18.00</td>
</tr>
<tr>
<td>2.</td>
<td>13.00</td>
<td>13.00</td>
</tr>
<tr>
<td>3.</td>
<td>14.00</td>
<td>14.00</td>
</tr>
<tr>
<td>4.</td>
<td>1.00</td>
<td>2.55</td>
</tr>
<tr>
<td>5.</td>
<td>5.00</td>
<td>6.30</td>
</tr>
<tr>
<td>6.</td>
<td>20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>7.</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>8.</td>
<td>16.00</td>
<td>16.00</td>
</tr>
<tr>
<td>9.</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>10.</td>
<td>12.00</td>
<td>12.00</td>
</tr>
<tr>
<td>11.</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>12.</td>
<td>11.10</td>
<td>11.10</td>
</tr>
</tbody>
</table>

Table 2. Kinematic chain elongation in mm, left and right micrometric devices, boys.

<table>
<thead>
<tr>
<th>Boys</th>
<th>Left, mm</th>
<th>Right, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>7.57</td>
<td>8.10</td>
</tr>
<tr>
<td>2.</td>
<td>5.00</td>
<td>4.80</td>
</tr>
<tr>
<td>3.</td>
<td>3.90</td>
<td>8.14</td>
</tr>
<tr>
<td>4.</td>
<td>3.80</td>
<td>3.30</td>
</tr>
<tr>
<td>5.</td>
<td>7.70</td>
<td>8.10</td>
</tr>
</tbody>
</table>
A recent study by Stoytchev et al. (2020), analyzed the experimental mechanical properties of synovial fluid and cartilage and their constitutive models, as well as their dynamic interaction under load. Due to the greater strength of the bones, their deformability during joint loading is not taken into account. The results can be summarized as follows:

- Synovial fluid is a dialysis of blood plasma and hyaluronic macromolecules, which lead to non-Newtonian rheological properties such as viscoelasticity and pseudoplasticity;
- From a mechanical point of view, cartilage is a porous, viscoelastic material consisting of three phases: solid phase, about 20% by volume, from folded collagen with a pore size of about 60 angstroms; interstitial fluid, normally 80% of the volume; a combination of different ions;
- Intensive experimental hydro-mechanical studies and modeling of processes in synovial joints have been performed since the early 1980s, mainly by Mow and his coworkers (Mow, Lai, 1979), Mow et al.,1980). It was found that:
  a) the rheological properties of cartilage are best described by the quasi-linear viscoelastic model of Fung (Fung, 1981);
  b) the interstitial fluid is transported through the porous cartilage according to Darcy’s law, the interaction between the deformable porous matrix and the fluid determines the so-called viscous friction;
  c) the biomechanical processes in the joint capsule are determined by the rheological properties of the cartilage and synovial fluid, on the one hand, and by the applied load, on the other hand;
  d) constitutive models (Mak, 1986), (Setton, Zhu, Mow, 1993) agree best with experimental results.

The widespread use of nuclear magnetic resonance (NMR) in research has made it possible to elucidate in vivo some processes in the joint capsule at certain loads. For example, Cotofana et al., (2011) found that cartilage thickness decreased to 5.2% with a knee load of 50% of body weight. Herberthold et al., (1999) received a 44% deformation of the cartilage of the kneecap under a load of 150% of body weight. For the first time, they also determine the amount of fluid flow from the cartilage into the capsule cavity. In these studies, however, the load is on the feet and does not involve muscle groups. Also, the load is selected to be proportional to the body weight of the studied participant. While in the experimental design of the present study each participant applies

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an isometric load according to their individual capabilities.

An in-depth review Eckstein, Hudelmaier, Putz (2006), found that physical activity (going downstairs, running and cycling) led to a slight deformation of the articular cartilage, which recovered after 90 minutes. Studies by the Kubo group (Kubo, Kanehisa, Fukunaga (2001) and (2002)), show that isometric exercises increase the volume of muscle groups up to 7% as well as their strength and Young’s modulus.

Recently, Ranchev et al., (2019) reported a study concerning the volume change of the knee joint capsule during isometric stretching. These data experimentally showed that in active isometric stretching there is a change in the distance between the cartilaginous surfaces of the femur and tibia (femur, tibia), which is associated with changes in the size of the muscle-tendon block of adjacent muscle groups due to their contraction (Figure 5).

![Figure 5](image)

**Figure 5.** Reduction of the distance between the cartilaginous surfaces of the femur and tibia in isometric stretching. A). At rest; B). At isometric stretching.

**DISCUSSION**

The main purpose of the stretching exercises is to achieve better performance of the muscles in sports, rehabilitation, and everyday activities. The synovial joints serve as a critical unit in realizing movements due to mechanical and biochemical processes inside the joint cavity. Eckstein, Hudelmaier, Putz (2006) suggested that human cartilage deforms very little in vivo during physiological activities like deep knee bends, static loading, running, cycling training bike and recovers from deformation within 90 min after loading.

For the present, the quantitative measurement of the forces developed by the muscles during stretching is practically impossible due to the different individual anatomical structure, the many connections with tendons and bones, as well as the individual biomechanical muscle properties. Therefore, for the indirect determination of these forces, structural mechano-mathematical models are used, for the input data of which EMG signals are used. It is reported that developed models from different author teams are successfully used for such calculation (Raikova, (2020)). A future task for the presented experimental model (Figure 3) is to quantify the muscular forces causing the observed elongation of the kinematic chain of the upper limbs and to examine the relation be-
tween the magnitude of these muscular forces and obtained kinematic chain extension.

The evaluation of the muscular forces acting on the joints of the kinematic chain of the upper extremities in the presented experimental model in Figure 3 would allow clarifying the processes inside the joint capsule. The most important of these is a change in the distances between the cartilaginous surfaces of the bones that make up the joint. These muscle forces cannot be calculated directly because the number of unknown muscle forces and reactions in the joints is much larger than the equilibrium equations that can be written. Therefore, in most cases, modeling and optimization methods are used, choosing an optimization function according to physiological considerations (Raikova, Prilutsky, 2001).

The muscle post isometric relaxation (PIR), which is a result of muscle energy technique, is an important contribution to reported “paradox”. The post-isometric relaxation technique begins by placing the muscle in a stretched position. Then an isometric contraction is exerted against minimal resistance. Relaxation and then gentle stretch follow as the muscle releases (Lewit, Simons, 1984) (Shenouda, 2012). It was found that this technique leads to excellent relaxation and an improved resting length of the hyperactive muscles (Lewit, Simons, 1984; Shenouda, 2012; Liebenson, 2007).

CONCLUSION

In isometric stretching an elongation in the linear dimensions of the kinematic chain of the upper limbs is observed.

This study reviews the results of surveys related to the elucidation of the mechanism of the joint response in isometric stretching. They can be summarized in several groups of factors: a) deformation of articular cartilage; b) hydro-mechanical effects and rheological behavior of synovial fluid; c) deformation of the joint capsule; d) changes in the mechanical properties of muscle tissue during the generation of force loads; e) viscoelastic behavior of the muscle-tendon block; f) muscle post-isometric relaxation (PIR) phenomenon (Lewit, Simons, 1984); g) intra articular processes and movements, respondent to joint loading.

The main question is how to estimate the separate contributions of the listed seven (probably and more) factors, related to the elucidation of the mechanism of the extension of the stretched kinematic chain of the upper limbs. The difficulty is related to the interaction between these factors, which makes the analysis of the observed phenomenon complicated.

This work focuses on the intra articular processes and its biomechanical explanation. The described results contribute to the elucidation of the mechanism of the joint response in isometric stretching. This response depends on many factors, which interact with one another, and can be applied not only to stretching but to all human movements.

These basic biomechanical processes inside the synovial joints are governed by mainly three factors - mechanical properties of articular cartilage and synovial fluid, from one side, and on the loading imposed on the joint, from the other side (Stoytchev et al., 2020).

1) Synovial fluid (dialysate of blood plasma and hyaluronic acid protein (HAP) complex) behaves as non-Newtonian fluid with pseudo-plasticity and visco-elasticity.

2) Articular cartilage - porous, viscoelastic material consisting of three principal phases: a) a solid phase, which is composed predominantly of a densely woven, strong, collagen enmeshed with proteoglycan macromolecules. The collagen and proteoglycan network form a porous, fiber-reinforced, composite solid matrix; b) a fluid phase, which is water (normally 80% by wet weight); and c) an ion phase.
3) Mechanical load applied on the joint, mainly depends on the muscular forces, load conditions and body pose.

The estimation of the mechanical load applied on the joints is the next step to clarification of the “paradox” presented in this study. Finally, the loads imposed on the joint, and especially their magnitude and velocity of application, predispose the intensity of the hydraulic processes inside the joint cavity like permeability of collagen matrix, drain of interstitial fluid etc. To our knowledge, those effects are not sufficiently examined for the moment.

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EFFECTIVENESS OF INDIVIDUALIZED APPROACH FOR PHYSIOTHERAPY OF CHRONIC SHOULDER PAIN AND PHYSICAL FUNCTIONING IN ELITE ATHLETES WITH PHYSICAL DISABILITIES

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ABSTRACT
Objective: To study the potential effectiveness of individual physiotherapy program for wheelchair athletes with shoulder girdle persistent pain and dysfunctions.

Materials and methods: Thirteen athletes, members of the Bulgarian National Teams in wheelchair basketball and track and field athletics, with mean age 40.6 ± 10.9 participated in the study. The studied athletes had had a history of persistent pain and shoulder girdle dysfunctions for more than 6 months. Individual physiotherapy programs were applied to the participants for a period of two weeks. The selection of techniques was based on the initial assessment and evaluation. The participants were evaluated before treatment, after the first week of treatment, and at the end of the period with the use of the following specific questionnaires and tests: Goniometry of shoulder flexion and horizontal adduction, Apley’s Scratch test, Active compression test of O’Brien (ACT), Athletic shoulder outcome rating scale and Wheelchair User’s Shoulder Pain Index (WUSPI).

Results: Post-treatment effects demonstrated a significant (p<.05) increase in shoulder flexion (14.6° for the right and 12.7° for the left) and horizontal adduction (21.9° for the right and 18.8° for the left). A corresponding increase in the scores for the Athletic shoulder outcome rating scale was found with 10.92 points difference to the initial score (p<.05). The WUSPI demonstrated a non-significant improvement of 0.69 points. The results of ACT and Apley scratch test showed a non-significant decrease of 23.1% for the right shoulder and 15.4% decrease for the left shoulder after 7 days of treatment. Those results remained unchanged in post-treatment testing.

Conclusion: This study showed that the individual physiotherapy programs are effective in the management of wheelchair athletes with chronic shoulder pain. The involvement of Mulligan’s manual therapy techniques combined with other types of exercises for the shoulder and the trunk are beneficial for wheelchair athletes with chronic shoulder pain.

Key words: Wheelchair athletes, Pain, Physiotherapy, Shoulder, Shoulder girdle.

INTRODUCTION
Shoulder disorders are a common problem in wheelchair users and many of them experience shoulder pain (Finley et al., 2004; Samuelson et al., 2004; Curtis et al., 1995; Curtis et al., 1999; Ballinger et al., 2000; Fullerton et al., 2003). Shoulder pain is caused by many fac-
tors, but most of the studies in the field report that increased shoulder load and the repetitive stress of everyday wheelchair handling and transfers are among the most prevalent ones (Fullerton et al., 2003; Nyland et al., 1997).

In elite wheelchair athletes, upper limb injuries are frequent, with shoulder injuries being the most common (Fairbairn et al., 2019; Tuakli-Wosornu et al., 2018). The cause of shoulder problems in wheelchair athletes is probably multifactorial and is difficult to identify (Heyward, 2017). Some authors concluded that there was a lack of knowledge of the cause of complaints and that further research should be performed to better understand mechanism and factors involved (Fullerton et al., 2003 Chung et al., 2012). The risk for shoulder pain further increases when wheelchair users also participate in different wheelchair sport activities (Crespo-Ruiz et al., 2011; Curtis et al., 1999; Pérez-Tejero et al., 2006). About 80% of wheelchair basketball players reported shoulder pain-related activities of daily living (ADL) or sports activities (Curtis et al., 1999; Pérez-Tejero et al., 2006). Overhead movements involved in many daily living activities and also many sports activities with even higher load may promote shoulder pain (Curtis et al., 1995; García-Gómez et al., 2017; Curtis et al., 1985).

According to some studies, elite wheelchair athletes experience many injuries including a high prevalence of rotator cuff pathology (Lim et al., 2014; De Witte et al., 2017; Tsunoda et al., 2016). Furthermore, it has been shown that encouraging shoulder stability and mobility are fundamental training contents to prevent postural changes (García-Gómez et al., 2019). Often the pain is produced in the end range of elevation movements. They characterize the main part of the overhead sport activities. The full possible end range of upper limb elevation movements was found to be related to trunk mobility too (Requejo, 2008). Improvement in thoracic extension and rotation in able-bodied people is known to have the highest positive impact in the end range of shoulder flexion (Barrett et al., 2016). 15° improvement in thoracic extension resulted in improving shoulder function (Peek, 2015). However, it is relevant to note that no research, to our knowledge, has been carried out that deals with the impact of thoracic extension and rotation improvements to the shoulder range of motion of wheelchair users. In this regard, many studies have been developed to analyze wheelchair users and make the link between the existing pathologies and the reported rates of shoulder pain. Therefore, the majority of the studies focused on treatment programs and protocols are often based on structural changes found by imaging (Curtis et al., 1999; Mulroy et al., 2011; Van Straaten et al., 2014; Nawoczenski et al., 2006; Satyavanshi et al., 2017). This seems a bit controversial as recent studies show that nearly 60% of the investigated wheelchair users report shoulder pain but the imaging results do not identify any significant associations between pain and the prevalence of shoulder pathologies. In average, the pain is considered mild in intensity as evidenced by relatively low WUSPI scores for dominant and non-dominant shoulders (Divanoglou et al., 2018; Dyson-Hudson et al., 2004; Curtis et al., 1999; Morrow et al., 2014).

Muscle activity and changed kinematics is often associated with chronic pain in wheelchair users (Mulroy, 2011, Van Straaten, 2014). Articular receptors can influence the function of the muscles around the joint as explained by arthrokinematic reflex (Makofsky et al., 2007). Dysfunction, pain, and inflammation of the joints lead to neural inhibition of the surrounding muscles, which is known as arthrogenic muscle inhibition (Rice et al., 2010). This failure to activate the muscles was observed in the shoulder region as well (Diederichsen et al.,
Experimentally induced subacromial pain was found to reduce the force of contraction of infraspinatus muscle while performing an isometric external rotation (Stackhouse et al., 2013). However, by altering the peripheral input to the spinal centres the arthrogenic muscle inhibition can be reduced (Makofsky et al., 2007). Pain reduction in the shoulder joint was shown to improve the function of the surrounding muscles (Steenbrink et al., 2006). Joint mobilization can influence the efferent motor output to the surrounding muscles by increasing the afferent input through stimulation of mechanoreceptors of the joint. Mulligan’s mobilization with movement (MWM) is a joint mobilization technique where an accessory glide is given manually to one of the joint surfaces while the participant performs the painful movement actively (Mulligan, 2019).

One of the goals of MWM is to achieve immediate pain relief in the applied joints of the body (Neelapala, 2017). The mechanisms of action and effects of MWMs include manual correction at the joint and neurophysiological effects on the function of the surrounding muscles (Vicenzino et al., 2007, Dimitrova, 2006). A study reported a reduced muscle activity in the shoulder muscles during the application of MWM using a postero-lateral glide in asymptomatic individuals (Ribeiro et al., 2016). The positive instant results of the manual techniques are found to predispose patients to greater motivation and confidence (Teys et al., 2008).

Consistent among several of the intervention studies for wheelchair athletes with shoulder pain to date is that the exercise protocols combine global strengthening of the scapular muscles with glenohumeral strengthening and stretching. In this study, we tested the efficacy of a series of therapeutic exercises in combination with individually selected Mulligan manual mobilisations designed to address shoulder pain in elite wheelchair athletes. In this regard, many studies have been developed to analyze wheelchair users (Curtis et al., 1999 Mulroy et al., 2011; Van Straaten et al., 2014; Nawoczenski et al., 2006; Satyavanshi et al., 2017). However, it is relevant to note that no research, to our knowledge, has investigated the impact of an exercise program on persistent shoulder pain of elite wheelchair basketball players and track and field athletes. The benefits of exercise were shown to be augmented when done in combination with several manual therapy techniques for able-bodied people with shoulder pain (Kuhn et al., 2009). Such findings were not reported in these individuals using MWM techniques. Regarding this, we could not find any research about the Mulligan manual mobilisations for wheelchair users with shoulder pain.

Therefore, the purpose of this study was to determine the effects of a 2-week intervention on shoulder pain and functional disability in elite wheelchair athletes with persistent symptoms of shoulder pain.

**MATERIAL AND METHODS**

This investigation was performed in accordance with the ethical standards of the Helsinki Declaration. All research procedures including testing protocol received approval from the Ethical board of the National Sports Academy. University-approved informed consent was obtained from the surveyed athletes.

**Participants**

Thirteen (11 male and 2 female) athletes with mean age 40.6±10.9 participated in the study. All participants were members of the Bulgarian National Teams in wheelchair basketball and track and field athletics (the disciplines of javelin throw and shot put) at the moment of the study. The studied athletes had had a history of persistent pain and shoulder girdle dysfunctions for more than 6 months.

Information including age, sex, date of SCI,
total time of wheelchair dependence, previous operative procedures, and injuries of the upper extremities was obtained by interviewing and reviewing the medical records of all members of Bulgarian National Teams in wheelchair basketball and track and field athletics (the disciplines of javelin throw and shot put). These patients were asked to participate in this study. Inclusion criteria for the subjects included a current history of unilateral or bilateral shoulder pain lasting 6 months or longer and localized in the shoulder joint region; at least 2 of the following findings: painful arc on active scapular plane abduction and horizontal adduction, pain with shoulder motions (flexion, abduction, internal or external rotation), or painful palpation around the shoulder joint (anteriorly, posteriorly, or at greater and lesser tubercles); shoulder pain during training and sports activities; and shoulder pain during transfers and weight-relief raises. The exclusion criteria included history of fractures or dislocations in the shoulder from which the subject had not fully recovered, upper limb dysesthesia pain as a result of a syrinx or complex regional pain syndrome, and history of cardiovascular or cardiopulmonary disease. An informed consent was obtained from all the subjects before participation in this study. Of 36 wheelchair athletes, 13 met the inclusion criteria and were recruited for this study. A total of 13 patients with paraplegia (2 women and 11 men) were ultimately included in the study. Before enrollment patients gave their written informed consent to participate in the study. Four clinicians were involved in the evaluation procedure.

During the study, the physiotherapy interventions were conducted daily so that they did not interfere and limit the training activity of the participants. All participants were advised to continue their training regime, consisting of one training per day with average duration of one hour and 35min. There were no competitions in their schedule for the treatment period of the study.

**Outcome measures**

The participants were evaluated in the beginning, after the first week of treatment, and at the end of the period using the following specific questionnaires and tests:

**Wheelchair User’s Shoulder Pain Index (WUSPI)** was specifically designed for patients with permanent disabilities, requiring the use of a wheelchair (Curtis et al., 1995). It covers general issues, related to a person’s involvement and capacity, when performing everyday activities, including moving in the city, dressing, eating, etc. The Wheelchair User’s Shoulder Pain Index (WUSPI) is a simple and effective self-report questionnaire for quickly measuring the functional cost of shoulder pain in wheelchair users. The WUSPI targets task-specific limitation resulting from shoulder pain (4 subsections), including wheelchair transfers, wheelchair mobility, self-care, and general activities. It is a 15-item self-report questionnaire in which patients are asked to rate, on a 10-cm visual analogue scale, the amount of pain they have experienced in their shoulder/s over the past week when performing everyday activities. The activities include transfers, mobilizing in a wheelchair, dressing and washing, sleeping, driving, performing household and other daily activities. The visual analogue scale is anchored at one end with ‘no pain’ and the other end with ‘worst pain ever experienced’. The scores are tallied with the total score ranging from 0 to 150 points, where a higher score indicates more severe shoulder pain than a lower score. The score can be calculated by summing only the scores of questions that are relevant and answered. This score is then divided by the total number of questions that are answered and then multiplied by 15 to maintain the original scale (i.e.,
from 0 to 150 points) (Curtis et al., 1995; Curtis et al., 1999; Yildirim et al., 2010).

Athletic shoulder outcome rating scale (ASORS). This questionnaire was specifically designed for athletes with an accentuated predominant upper limb load. It provides information about the level of pain and performance of athletes during training activities and the performing of specific movements, required in their particular sports (Tibone et al, 1993; Magee, 2016). The questionnaire combines subjective and objective evaluations. The subjective evaluation is allocated 90 points, which include pain, strength/endurance, stability, intensity, and performance. The other 10 points are allocated for objective testing. The ASORS may be more sensitive for high-level athletes (Plancher et al., 2009). The overall results depending on the point allocation can be: Excellent - 90-100 points; Good - 70 - 89 points; Fair - 50 - 69 points and Poor - less than 50 points (Magee, 2016). Although this outcome assessment tool has not been validated in the literature, it was used because of its unique parameters for evaluation of outcome in the athletic shoulder (Reynolds et al., 2008). Typical shoulder outcome scales were developed for the general population and do not accurately assess outcomes in athletes. The subjective part of the Athletic Shoulder Outcome Rating Scale measures shoulder function in athletes based on pain, strength and endurance, stability, intensity, and performance. The individual categories are weighed according to the importance for the overall outcome with performance being weighed more than all the other categories combined (Reynolds et al., 2008).

Goniometry was used to assess the active pain free range of motion. Two specific directions of the movement were selected - flexion (elevation) and horizontal adduction of the shoulder because they were commonly limited due to pain for all the participants in the study. The point of the active range where participants reached pain was noted and recorded. All participants demonstrated pain limiting the active movement only in those two specified directions, flexion and horizontal adduction. The full possible active pain free range of motion was assessed to evaluate the patient’s pain free active range of motion (Nitin, 2013). The goniometry procedure follows the guidelines of Van Ost (Van Ost, 2013).

Goniometry - flexion

The subject is positioned in sitting with the knees flexed to stabilize the lumbar spine. The elbow is extended, and the forearm is in mid position between supination and pronation. The shoulder should be in a position of maximal pain free flexion at the end of the movement. The elbow should be in extension and the forearm should be in a neutral position. The goniometric alignment is: Axis - Near the acromion process, through the humeral head; Stationary arm - Aligned with the midaxillary line of the trunk; Moving arm - Aligned with the midaxillary line of the trunk; Moving arm - Aligned with the lateral midline of the humerus sitting the lateral epicondyle of the humerus. The scapula must be stabilized against a supporting surface to prevent elevation, upward rotation, and posterior tilting. The clinician uses his/her hand to stabilize the scapula. Common substitutions in an attempt to gain more shoulder flexion may include lumbar hyperextension, shoulder abduction, or scapular elevation. These substitutions may occur because of limitations at the glenohumeral joint or as a result of pain during testing.

Goniometry - horizontal adduction

The subject should be sitting with the shoulder in neutral rotation. The shoulder joint is flexed to 90 degrees and the elbow is flexed to 90 degrees. The shoulder should be in a position of maximal pain free horizontal adduction at the end of the movement.
Stationary arm - Aligned along the midline of the shoulder siting the base of the neck; Moving arm - Aligned along the midline of the humeral shaft, siting the lateral epicondyle of the humerus. The thorax must be stabilized against the back of a chair or supporting surface to prevent rotation.

Additional clinical information about the signs in the shoulder complex was obtained, by the application of two specialized tests - Apley's Scratch test and Active compression test of O'Brien. Both tests were randomly selected from the list of the most applied clinical tests for patients with shoulder pain (Magee, 2016). Both Apley and Active compression test of O'Brien were not used as selection criteria. The tests were applied at the beginning, after the 7th day and post treatment.

In Apley’s Scratch test the patient is asked to put his/her arm above the head and drive it behind the neckline to touch his/her upper back. This test analyzes the rotation of upward, external and elevation (Anderson et al. 2011). During physical examination, if the patient is having pain provocation, then the physical assessment is marked positive (Magee, 2016).

Active compression test of O’Brien. The patient is placed in standing position with the arm forward flexed to 90° and the elbow fully extended. The arm is then horizontally adducted 10° to 15° (starting position) and medially rotated so the thumb faces downward. The examiner stands behind the patient and applies a downward eccentric force to the arm. The arm is returned to the starting position and the palm is supinated so the shoulder is laterally rotated, and the downward eccentric load is repeated. If pain on the joint line or painful clicking is produced inside the shoulder (not over the acromioclavicular joint) in the first part of the test and eliminated or decreased in the second part, the test is considered positive for labral abnormalities (Magee, 2016).

**Intervention**

All participants followed detailed individual programs consisting of two parts. The first part with protocol applied for all participants in the study including mobility and resistive (with elastic bands) exercises in the upper extremities (Curtis et al., 1999; Mulroy et al., 2011; Van Straaten et al., 2014; Nawoczenski et al., 2006; Satyavanshi et al., 2017). The second part of the program included specific Mulligan manual techniques, individually selected according to the symptoms of each participant. To assure the quality and consistency of the individual physiotherapy program, a qualitative analysis was developed based on the expert opinions of health and sports professionals, including a sports physician, physiotherapists and coaches (García-Gómez et al. 2017). The second part of the individual programs were individually selected by the physiotherapy team of 4 people. All of them where certified Mulligan manual therapy practitioners (CMP). The selection of the techniques followed all guidelines of the concept and was based on the pain location, movement limitation and movement restriction due to pain (Mulligan, 2019; McDowell et al. 2013).

Based on the information and evidence available in the previous literature, individual physiotherapy programs were developed. They focused on the pain management, mobility and activity improvement in wheelchair basketball players and track and field athletes (the disciplines of javelin throw and shot put) with chronic shoulder pain and limitations. The content validity of the first part of the treatment program was demonstrated in previous studies (Curtis et al., 1999; Mulroy et al., 2011; Van Straaten et al., 2014; Nawoczenski et al., 2006). The proposed first part of program included:

Five resistive exercises with an elastic band (Blue color Thera-band) performed for scapula
retraction and depression, and shoulder rotation and adduction (two sets of ten repetitions, with 45 s of rest between sets). All exercises had to be performed without pain provocation. The detailed exercises were:

One hand horizontal rowing with accent for scapula retraction in the end position. Controlled protraction when going back to starting position in eccentric phase was required;

Shoulder internal and external rotation from starting position of the arm touching the unilateral side of the trunk and elbow in 90º;

Shoulder internal and external rotation from starting position 90º shoulder and elbow flexion;

Shoulder press (from 90º abduction of the shoulder) with an elastic band attached behind the patient on the level of the shoulder;

Mobility exercise for extension, rotation and lateral bending of the trunk from sitting position with back supported on the edge of the table (on the level of the inferior border of the scapulas) and hands behind the neck;

Mobility exercise for extension, rotation and lateral bending of the trunk from sitting position with back supported on the edge of the table (on the level of the inferior border of the scapulas) and hands holding a 300 gram, 1-meter long plastic bar placed on top of the shoulders and behind the neck.

Based on the information and evidence available in the literature, techniques for manual mobilization from the Mulligan concept were selected and applied. The techniques selected for the study were:

- Mobilization with movement (MWM), lateral-posterior glide of the glenohumeral joint for limited and painful flexion (Mulligan, 1999). The technique was performed by a physiotherapist with a patient seated. The physiotherapist stood on the contralateral side of pain, stabilizing the scapula posteriorly with one hand. The head of the humerus was translated posteriorly and laterally with the other hand, along the plane of the glenoid fossa. While the glide was sustained, the patient actively elevated arm through the plane of movement. Three sets of ten repetitions, with 45 s of rest between sets were applied in each treatment session (Hing, 2015).

- NAG’s - natural apophyseal glides (Mulligan, 2019). The technique was performed by a physiotherapist with a patient seated and well supported in a chair. The physiotherapist stood facing the patient in step stance posture stabilizing the patient’s shoulder/trunk. Painless oscillatory mid to end-range mobilization was applied in the plane of the facet joints on the spinous process or articular pillar. Mobilizations were applied 6 times on each level (working from cranial to caudal) and repeated 3 times (Hing, 2015).

- Reverse NAG’s for the cervicothoracic junction (Mulligan, 2019). The technique was performed by a physiotherapist with a patient seated and well supported in a chair. The physiotherapist stood facing the patient stabilizing the patient’s shoulder girdle and upper trunk. Painless oscillatory mid to end-range mobilizations were applied in the plane of the facet joints on the articular pillars. Mobilizations were applied 6 times on each level (working from caudal to cranial) and repeated 3 times (Hing, 2015).

The exercises and techniques were selected, and the programs were developed based on previous literature and clinical experience (Curtis et al., 1999; Mulroy et al., 2011; Van Straaten et al., 2014; Nawoczenski et al., 2006).

The two-week-long intervention involved treatment sessions once daily, amounting to 14 sessions in total during a mid-season training camp. The exercise program was performed by each participant individually under the super-
vision of a physiotherapist who also applied the selected Mulligan’s manual mobilizations throughout the study. All exercises and techniques were performed in a seated position.

**Statistical analysis**

The statistical analysis was performed with the Statistical Package for the Social Sciences (SPSS), version 23.0 for Windows (IBM corp. Inc., Chicago, IL, USA, 2015). The normality of all variables was tested with the Shapiro-Wilk normality test. Descriptive statistics (mean±standard deviation) were computed. The categorical data were presented as a percentage. Student t-test for paired samples (two-tailed) was used to evaluate the changes in goniometry results over time. Additionally, Cohen’s d effect size was used for quantitative measurement of the magnitude of the effect in the same variables. The McNemar test was conducted to determine the differences between proportions of positive answers in the Appley scratch test and Active compression test. The pre- and post-treatment differences in the scores of the Athletic shoulder outcome rating scale and Wheelchair User’s Shoulder Pain Index were tested by Wilcoxon Signed-ranks Test. A probability level of p < .05 was used to establish the significance for all the procedures.

**RESULTS**

The changes in the range of motion in flexion and horizontal adduction are shown in Table 1, Figures 1 and 2.

The pre-treatment measurements for the range of flexion in both shoulder joints were 149.2±17.1° for the right shoulder and 146.2±23.0° for the left. After 7 days there was a tendency for increasing the range in both shoulder joints, respectively 158.9°±18.6° for the right and 154.2°±20.6° for the left. Post-treatment results for flexion reached an average of 164.6°±18.2° for the right and 160.0°±20.2° for the left shoulder. The differences between the test results were statistically significant (Table 1).

Table 1. Range of motion in the shoulders – goniometry results (degrees)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-treatment</th>
<th>After 7 days</th>
<th>Post-treatment</th>
<th>Mean Difference B-A</th>
<th>Mean Difference C-B</th>
<th>Mean Difference C-A</th>
<th>Cohen's d (C-A) 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion – right shoulder</td>
<td>149.2±17.1</td>
<td>158.9±18.6</td>
<td>164.6±18.2</td>
<td>9.7</td>
<td>5.7</td>
<td>15.4</td>
<td>.87</td>
</tr>
<tr>
<td>Flexion – left shoulder</td>
<td>146.2±23.0</td>
<td>154.2±20.6</td>
<td>160.0±20.2</td>
<td>8.0</td>
<td>5.8</td>
<td>13.8</td>
<td>.63</td>
</tr>
<tr>
<td>Horizontal adduction – right shoulder</td>
<td>93.5±38.2</td>
<td>108.1±21.7</td>
<td>115.4±14.9</td>
<td>14.6</td>
<td>7.3</td>
<td>21.9</td>
<td>.41</td>
</tr>
<tr>
<td>Horizontal adduction – left shoulder</td>
<td>96.9±39.0</td>
<td>109.6±20.9</td>
<td>115.8±15.8</td>
<td>12.7</td>
<td>6.15</td>
<td>18.8</td>
<td>.45</td>
</tr>
</tbody>
</table>

*Note: The values are presented as mean ± SD. The differences between means were calculated by paired sample t-test. *p<.05

For horizontal adduction, the pre-treatment measurements were an average of 93.5°±38.2° for the right shoulder and 96.9°±39.0° for the left one. There was an increase within the range of motion after 7 days with 14.6° for the right and 12.7° for the left shoulder. The post-treatment results for the right shoulder indicated that horizontal adduction range of motion signifi-
Significantly increased to $115.4^\circ \pm 14.9^\circ$ ($p < .05$). The average left shoulder horizontal adduction significantly increased to $115.8^\circ \pm 15.8^\circ$ ($p < .05$).

Cohen (1988) stated that $d = .2$, .5 and .8 correspond to “small”, “medium” and “large” effects (Cohen, 1988). The effect size (Cohen’s d) for the flexion of the right shoulder is .87 and .63 for the left one and that corresponds to a ‘strong’ effect. For the horizontal adduction, the effect size is ‘medium’ with .41 for the right shoulder and .45 for the left one.

![Figure 1. Range of shoulders flexion (degrees)](image)

The percentages of positive cases in the Apley scratch test for the pre-treatment measures were the same for the right and the left shoulders 69.2% (Table 2). After 7 days of treatment, there was a reduction to 46.2% for the right shoulder (23.1% difference - Table 2).

![Figure 2. Range of shoulders horizontal flexion (degrees)](image)

<table>
<thead>
<tr>
<th>Test/variable</th>
<th>Pre Treatment</th>
<th>After 7 days</th>
<th>Post Treatment</th>
<th>%Difference B-A</th>
<th>%Difference C-B</th>
<th>%Difference C-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apley scratch test – right shoulder</td>
<td>69.2 % (9)</td>
<td>46.2% (6)</td>
<td>46.2% (6)</td>
<td>23.1%</td>
<td>15.4%</td>
<td>0 %</td>
</tr>
<tr>
<td>Apley scratch test – left shoulder</td>
<td>69.2% (9)</td>
<td>58.3% (7)</td>
<td>46.2% (6)</td>
<td>15.4%</td>
<td>7.7%</td>
<td>23.1%</td>
</tr>
<tr>
<td>Active compression test – right shoulder</td>
<td>53.8% (7)</td>
<td>30.8% (4)</td>
<td>30.8% (4)</td>
<td>23.1%</td>
<td>7.69%</td>
<td>0 %</td>
</tr>
<tr>
<td>Active compression test – left shoulder</td>
<td>38.5% (5)</td>
<td>23.1% (3)</td>
<td>23.1% (3)</td>
<td>15.4%</td>
<td>0 %</td>
<td>15.4%</td>
</tr>
</tbody>
</table>

*Note: The values are presented as percent (number). The differences between proportions were calculated by McNemar Test. * $p < .05$

For the left shoulder, the difference after 7 days was 15.4% (58.3% positive cases - Table 2). Post-treatment those results remained the same: 46.2% positive cases for the right shoulder and 58.3% for the left one (Table 2).

The pre-treatment percentage of positive
cases in the Active compression test of O’Brien for the right shoulder was 53.8% (Table 2). For the left one, it was 38.5% (Table 2). The testing after 7 days showed a non-significant decrease of 23.1% (30.8% positive cases) for the right shoulder and 15.4% (23.1% positive cases) decrease for the left shoulder. Those results remained unchanged in the post-treatment testing (Table 2).

The pre-treatment scores for the Athletic shoulder outcome rating scale (Table 3) were 70.31 ± 17.2. The post-treatment scores (81.23 ± 14.18) were significant with 10.92 difference to the initial score. The average pre-treatment score for the Wheelchair User’s Shoulder Pain Index (WUSPI) was 35.31 ± 28.96. The post-treatment score was 34.62 ± 28.60 demonstrating non-significant improvement of 0.69 (p = .57).

Table 3. Tests for complex function and activities: Athletic shoulder outcome rating scale (ASORS) and Wheelchair User’s Shoulder Pain Index (WUSPI) (scores)

<table>
<thead>
<tr>
<th>Test/Variable</th>
<th>Pretreatment</th>
<th>Post treatment</th>
<th>Difference</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASORS</td>
<td>70.31±17.2</td>
<td>81.23±14.18</td>
<td>10.92</td>
<td>.0015*</td>
</tr>
<tr>
<td>WUSPI</td>
<td>35.31±28.96</td>
<td>34.62±28.60</td>
<td>-0.69</td>
<td>.57</td>
</tr>
</tbody>
</table>

Note: The values are presented as mean±SD. The differences between means were calculated by Wilcoxon Signed-ranks Test. * p<.05

DISCUSSION

The purpose of this study was to assess the effects of a 2-week individual physiotherapy programs on elite wheelchair basketball and track and field throwing disciplines athletes with chronic shoulder pain.

Following a 2-week intervention program, there was significant improvement in flexion and horizontal adduction ER ROM. The increases of 15.4° (R) and 13.8° (L) in flexion ROM and 21.9° (R) and 18.8° (L) in horizontal adduction ROM are also considered clinically significant improvements in ROM as they are increases greater than 5° (Boone et al., 1978). Manual therapy Mulligan techniques combined with active pain free movements in the symptomatic directions are most probably responsible for the increase in external rotation ROM. In addition, the resistive exercises that were included also provided a dynamic stress to the adjacent joint structures and have positive neurophysiological effect. There are no other published studies on the effects of those techniques on wheelchair users with persistent shoulder pain. However, these findings are consistent with studies with able-bodied people (Teys et al., 2008). The same tendency is demonstrated in studies conducted in other joints of the body that have shown similar effects with the MWM techniques (O’Brien et al., 1998; Abbott et al., 2001; Paungmali et al., 2003b; Collins et al., 2004, Vicenzino, 2007). Many studies proposed that manual therapy may provide sufficient sensory input to activate the endogenous pain inhibitory systems (Sterling et al., 2001; Paungmali et al., 2003a; Souvlis et al., 2005). The combination of active pain free MWM (mobilizations with movement), trunk mobility and strengthening exercises resulted in an improvement in previously restricted ROM in shoulder joint (due to pain) in the wheelchair athletes included in our study. The exercises of the trunk aimed to gain mobility in the area and possibly affect the end range of shoulder flexion (Barrett et al., 2016; Peak, 2015). They were applied in a manner based on the throwing kine-
mathematics and mechanic similar to the sports of the treated athletes. Overhead throwing motion is a complex activity, involving the shoulder, trunk, and spine, that is achieved through the activation of the kinetic chain, to allow the sequential transfer of forces and motion which requires good pain free mobility in both shoulder joint and thorax (Chu et al., 2016).

After the intervention, the participants reported a reduction in WUSPI scores; however, this change was not statistically significant. While evidence shows that wheelchair athletes are experiencing shoulder pain, explaining this occurrence has been much more difficult. Many studies have looked at correlations between athlete demographics and shoulder pain, but there are still discrepancies regarding the cause of the pain. The average WUSPI score of all participants in our study before the intervention, 35.31±28.96 (N=13) was high in comparison to studies of manual wheelchair users, averaging 23.08 but comparatively low in comparison to other wheelchair athletes (Brose et al., 2008). Post treatment scores in our study where 34.62±28.60. Byung-chun et. al. reported an average WUSPI score of 44.42 for adapted table-tennis athletes and 54.69 for adapted archery athletes (Byung-chun et al., 206). Hooper et al., 2018 reported 39.75 reported an average WUSPI score of 44.42 for adapted rugby athletes (Hooper et al., 2018).

Curtis and Black reported that the WUSPI score was 15.6 ± 20.5 in 46 female wheelchair basketball players (Curtis, 1999) which matches with the score of Ustunkaya et al. 21.59 ± 20.11 (Ustunkaya, 2007). It seems like wheelchair athletes, practicing overhead sports like wheelchair basketball and throwing disciplines (track and field athletics) report less shoulder pain than those who participate in competitive sports without so much overhead activities like wheelchair table tennis and wheelchair rugby.

The Athletic Shoulder Outcome Rating Scale demonstrated ‘good’ results (score >70). The pre-treatment scores were 70.31±17.2 and the post-treatment scores (81.23±14.18). This demonstrates a significant improvement with 10.92 difference to the initial score. However, it is relevant to address that no research, to our knowledge, has been carried out using the Athletic Shoulder Outcome Rating Scale for elite wheelchair athletes. We did believe it was important to determine scores for the Athletic Shoulder Outcome Rating Scale in addition to their current status mainly because of its unique parameters for evaluation of outcome in the athletic shoulder.

There were some limitations to this study. There was no treatment group assigned to a control condition or conventional physiotherapy intervention removing the ability to compare the individual physiotherapy with other treatment approaches. However, our results act as a basis for further investigation into reported shoulder pain by wheelchair athletes, specifically elite wheelchair basketball participants and track and field throwers.

Further analysis should be done with a larger sample of more diverse wheelchair athletes to determine more accurate the long-term effect of individual physiotherapy programs on shoulder pain. Future studies should also search for preventative measures to any associations found in comparative studies. The future studies should be more generalizable to wheelchair athletes participating in other wheelchair sports.

CONCLUSION
There is a lack of literature about the short- and long-term effect of manual mobilization techniques on wheelchair users with chronic shoulder pain. Specific to elite wheelchair basketball players and throwing disciplines athletes, the results from our study show potential possibility to decrease the level of pain. Clin-
ical implications should include clinicians being more aware of the impact of shoulder pain of wheelchair users in their daily lives. This study shows that the individual physiotherapy program is effective in the management of wheelchair athletes with chronic shoulder pain. The involvement of manual therapy techniques, other types of exercises, such as scapular stability exercises, rotator cuff through range exercises, exercises for the anterior and posterior shoulder and trunk mobility exercises are beneficial for the studied elite wheelchair basketball players and track and field throwers with chronic shoulder pain.

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SELECTIVE ANDROGEN RECEPTOR MODULATORS (SARM) – A NEW TEMPTATION IN SPORTS. TYPES, MODE OF ACTION AND SIDE EFFECTS OF THEIR APPLICATION: REVIEW

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Medical University of Plovdiv, Bulgaria

ABSTRACT
The selective androgen receptor modulators (SARMs) are androgen receptor ligands that bind to androgen receptors on target cells and exhibit a more pronounced anabolic effect at the expense of the androgenic effect on the latter. The aim of the article is to explain what SARMs are and how they are connected with sports. We used over 300 articles for the last 20 years connected with SARMs. Recently, the interest in these new molecules and their use has grown significantly, including in sports, which has led to their listing on the WADA prohibited list. In recent years, a lot of data have been gathered, both on the mechanism of action of a number of steroidal and non-steroidal representatives of this class of substances and on the adverse side effects of their use, as the latter should be well-known to sports doctors and especially to amateurs practicing in their free time and willing to increase their muscle mass with a view to preventing any potential health risks.

Key words: SARMs, anabolic steroids, androgen receptor, ostarine, doping

INTRODUCTION
The selective androgen receptor modulators (SARMs) represent a new class of androgen receptor ligands that act similarly to anabolic steroids, but are selective in their effects, with anabolic predominance, and androgenic ones being relatively limited. This gives a number of advantages of SARM over the anabolic androgenic steroids, associated with avoiding some of the side effects of the latter, such as acne, liver damage, testicular atrophy, thickening of vocal cords, hair growth, menstrual disorders in women, etc. Therefore, they have potential use in patients with a number of diseases, such as amyotrophic lateral sclerosis (Lou Gherig’s disease), dermatomyositis, osteoporosis, breast cancer, sarcopenia, various types of cachexia, benign prostatic hyperplasia, and hypogonadism (Chen et al., 2005a; Zhang, Sui, 2013).

Due to the pronounced anabolic effect, the selective androgen receptor modulators are widely used in sports to improve physical performance and athletic achievements. However, since 2008, they have been included in the World Anti-Doping Agency (WADA) List of Prohibited Substances, falling under the category of “other anabolic agents” in Section S1.2 of this list (Thevis, Schaanzer, 2018).

Although there is currently no approved representative of SARMs as a drug, these preparations/substances can be purchased online, but a study of Van Wagoner et al., 2017 evidences that only 52% of the 44 products of-
ferred online and tested contained real SARMs (Van Wagoner et al., 2017). Moreover, they are also included as ingredients in some dietary supplements which poses a significant risk of their use in sports. In some cases, as a matter of fact, consumers are misled by masking the presence of SARM on the label, using a coded one instead of the trade name of the substance (for example, MK-2866 or GTx-024 is indicated as an ingredient, instead of Ostarine).

Some of the most widespread and used preparations of this group are Ostarine and Andarine (Geyer et al., 2014). To carry out doping-control in sports in order to prove the use of SARM, various screening methods (gas chromatography, liquid chromatography and mass spectrometry) are used to detect them or prove the presence of their metabolites in blood or urine (Thevis et al., 2008; Thevis et al., 2008; Thevis et al., 2011).

With regard to their chemical structure, SARMs can be divided into two main groups: steroidal and non-steroidal. The steroidal group of SARM representatives have been known since as early as the middle of the last century (Bhasin, Jasuja, 2009).

The steroidal types of SARMs are obtained through structural changes in the molecule of testosterone. By removing the 19-methyl group, an increased anabolic effect of testosterone is achieved. Replacement of 7-alpha alkyl group reduces the interaction with the enzyme 5-α reductase and increases its tissue selectivity. Replacing the 17-alpha alkyl group increases the half-life of testosterone.

The first non-steroidal SARMs were presented in 1998 and since then there has been a growing list of substances of this group, some of which are drug candidates and many of them are currently under clinical trials (Chen et al., 2005a). Non-steroidal SARMs are grouped into different classes: aryl propionamide analogues, bicyclic hydantoin analogues, quinolones, tetrahydroquinoline analogues, butanamides, benzimidazoles. The first discovered class is that of aryl propionamides. The number of representatives of the different classes is constantly increasing.

Narayanan et al., 2008 and Bhasin, Jasuja, 2009 and Jasuja et al., 2012 represent very adequately the chemical structure of the two main groups of SARMs (Bhasin, Jasuja, 2009; Jasuja et al., 2012; Narayanan et al., 2008) (Table 1) and (Table 2).

Table 1. Structure of steroidal representatives of SARM
MATERIALS AND METHODS

Inclusion criteria
The aim of this review is to make it clear for all sportsmen (professional or amateur) what to expect from SARMs (which are the different types and what is their mechanism of action) and to present the adverse side effects and possible risks of their usage. Firstly, for an article to be included in our review it had to be connected with SARMs. Secondly, we used only the articles which provided information about SARMs in general, their role in sports (different methods to detect them in doping control), their mechanism of action and their adverse side effects no matter in animals or in people. The articles used were available in English and were open access.

Exclusion criteria
There were a lot of articles connected with SARMs which we did not include in our review. The main reason for them not to be included is that they do not provide the type of information we were looking for. They give detailed information about the chemical structure and development of SARMs and the process of their synthesis and discovery. As we already explained this is not the focus of our review and such articles were considered irrelevant by us. The review is based on 32 articles.

RESULTS
SARMs perform their effects after the ligand binds to the androgen receptor (AR) (Figure 1) by genomic mechanism. AR is coded

| Table 2. Structure of non-steroidal representatives of SARM |
|-----------------|-----------------|-----------------|
| Chemical type   | Structure       | Examples        |
| Anabolic analogs| ![structure](image) | Ostarine, andarine |
| Bisphosphonate analogs| ![structure](image) | SME-008239 |
| Quinolines      | ![structure](image) | LGD-5335, LGD-4041 |
| Tetracycline analogs | ![structure](image) | Kaken Pharmaceutical, S-8055 |
| Benzoimidazoles | ![structure](image) | Johnson and Johnson's benzoimidazole derivative |
| Steroid analogs | ![structure](image) | Select SARM based on butanamide scaffold |
by a gene that is located on the X chromosome (Narayanan et al., 2018). AR is a transcription factor and consists of three main domains: N-terminal domain (NTD) which modulates the transcription activation; DNA-binding domain (DBD) which binds to androgen response elements of DNA; C-terminal ligand-binding domain (LBD). There is also a hinge region between DBD and LBD (Gao, 2010).

AR is located in the cytosol of the cell because its ligands are liposoluble and can go through the cell membrane. After the ligand binds to the receptor, initially, conformational changes in the receptor occur. The heat shock proteins and chaperons associated with it are released. Then, the obtained complex moves to the cell nucleus. There, an interaction with the nuclear DNA occurs. Thus, AR may activate target genes that are involved in the regulation of a number of physiological processes. However, its transcriptional activity may be affected by proteins known as co-regulators. They are divided into co-activators which increase transcriptional activity, and co-repressors which decrease it.

Figure 1. Diagram of the domains of the androgen receptor (AP) and of the gene which encodes it (after Lonergan P.E. & Tindall D.J.) (Lonergan, Tindall, 2011)

The mechanisms by which tissue selectivity of SARM is achieved are not fully understood, but there are different hypotheses. Testosterone and anabolic androgenic steroids (AAS), under the action of the enzyme 5-α reductase, are converted into dihydrotestosterone (DHT) and other metabolites, which have greater biological activity and more pronounced effects on the genitals. SARMs are not susceptible to the action of this enzyme which helps to demonstrate their tissue selectivity (Gao et al., 2004). Another enzyme whose action is associated with side effects when taking AAS or testosterone is aromatase. It converts androgens into female sex hormones (estrogens), which are also responsible for the abovementioned side effects. Non-steroidal representatives of SARM are not susceptible to the action of this enzyme as well (Bhasin, 2015).

The mechanisms of tissue selectivity of SARM are performed regardless of their pharmacokinetic profile (Vajda et al., 2009). For example, the local tissue concentration of LGD-3303 was found to be higher in the prostate than in the muscles, despite the greater SARM in the muscles. The interaction of the androgen receptor with the various co-activators and co-suppressors is very essential. When DHT, testosterone or AAS bind to AR, the induced conformational change of the re-
ceptor leads to interaction with some co-regulators, and when binding SARMs to AR, the conformational change and co-activators with which AR interacts, are others (Narayanan et al. 2008; Narayanan et al., 2018). Similar data are presented by Furuya K. et al., who found that in an osteopenic model in female rats, after binding to AR, DHT caused the receptor to interact with the co-regulators TIF2, SRC1, β-catenin, NCoA3, gelsolin and PROX1 (Furuya et al., 2013). After S-101479 is bound to AR, the selection of co-regulators is different, and the receptor interacts only with the co-regulators gelsolin and PROX1, which is sufficient for the performance of tissue selectivity. More than 200 co-regulators are known to activate or suppress various target genes.

After binding to AR, DHT and SARM increase the phosphorylating activity of various kinases (Bhasin, Jasuja, 2009). For example, a non-steroidal SARM representative of the aryl propionamide class mediates its effects through the kinase pathways: MEK, ERK, p38 MAPK and others. While DHT uses the kinase pathways: PI3K, PKC, ERK and others (Narayanan et al., 2008). This shows that the two groups of ligands use different signalling pathways.

The conformational change caused by the classical agonists of AR (testosterone or AAS) favours the classical intramolecular N-terminal/C-terminal interaction (N/C interaction). This interaction is essential for the selection of certain co-regulators, for the transcriptional activity of AR and for the modulation of target genes. In the synthesis of SARM, the aim is to bring about a conformational change which does not stimulate this N-terminal/C-terminal interaction (N/C interaction). This would lead to the manifestation of the desired tissue selectivity by selecting other co-regulators and activating other target genes (Sathya et al., 2003). Antagonizing the N-terminal/C-terminal interaction (N/C interaction) leads to incomplete activation of the receptor, and to implement the effects on the prostate and seminal vesicles, it is necessary to fully activate AR (Schmidt et al., 2010). Through this mode of action, the representative of SARM TFM-4AS-1 exhibits anabolic effects in osseous and muscular tissue, without performing activity in the prostate (Schmidt et al., 2009).

SARM can also modulate the activity of the androgen receptors by inhibiting their transport to the cell nucleus (Roy et al., 2001). To implement their effects, SARM modulate AR in the muscular satellite cells (the stem cells of the striated muscles). Dubois et al., 2015 prove that anabolic effects are manifested in the other muscular cells as well (Dubois et al., 2015).

The established mechanisms of action of SARM make them an attractive future option in the treatment of a great number of diseases, such as osteoporosis, cachexia, sarcopenia, benign prostatic hyperplasia, neurological diseases with cognitive deficits, hypogonadism, sexual dysfunction, breast cancer and for the effective contraception in men. It should be considered, however, that their use, including by athletes, is also associated with a number of adverse side effects (Geyer et al., 2014). However, most of them are of low frequency and manageable. The most common ones are related to elevated liver enzymes and changes in various lipid fractions. There are still insufficient data on what the side effects of SARM would be in their long-term use. However, SARMs are thought to be far more sparing than AAS. AAS provoke responses from the body which very often significantly reduce the quality of life. Some of them can even be fatal.

What are references to date on the side effects of the use of SARM in healthy people and in experimental models in humans and animals?

For example, healthy men taking LGD-
4033 for 21 days were found to have decreased plasma levels of the sex hormone binding globulin (SHBG), triglycerides, HDL, FSH (Basaria et al., 2013). The changes found were manageable, with lipid and hormone concentrations returning to normal after discontinuation of the intake of LGD-4033.

Administration for 2 weeks of the selective modulator C-6 in intact rats caused a decrease in gonadotropic hormone and serum testosterone levels, and after ten weeks a suppression of spermatogenesis (Chen et al., 2005b).

In a postmenopausal model of osteoporosis in female rats, Ostarine was found to cause uterine weight gain and increased plasma phosphorus concentration (Hoffmann et al., 2019).

Adverse reactions observed in the use of Ostarine in humans include febrile neutropenia, pneumonia and progression of the malignant disease in patients who have it (Dobs et al., 2013).

In a large-scale experiment with women who suffer from sarcopenia, it was found that the intake of MK-0773 does not cause androgenization, but in some of the respondents, there is, albeit transient, an increase in transaminase liver enzymes (Papanicolaou et al., 2013).

Another study of healthy men and women in postmenopausal age found that the administration of GSK2881078 caused a decrease in HDL and SHBG. In women, these effects have occurred even at lower doses than in men. One woman was reported to have a rash, and two men were found to have elevated creatine phosphokinase levels after physical exercise (Clark et al., 2017).

The selective modulator RAD140, in various in vivo and in vitro models, was found to cause decreased appetite and weight, elevated liver enzymes ASAT and ALAT, as well as hypophosphatemia (Hamilton et al., 2019).

After the application of the new representative of SARM - PF-06260414 in healthy people of different ethnicities (Japanese and people from countries more to the West), the tolerance of the preparation is good, but there are slight adverse effects, such as headache and increased ALAT (Bhattacharya et al., 2016).

**CONCLUSION**

There are still insufficient data in literature on the effects of SARM when used in combination with physical exercise. Studies are needed in this aspect to determine possible side effects, to establish whether SARM will enhance the effects of the training itself, or just the opposite – will have an antagonistic effect on some of them.

Despite the described side effects of their use, the selective androgen receptor modulators are a promising alternative for their inclusion in the treatment of a number of diseases, although among them there is still no officially approved drug. They could be used as a replacement therapy instead of androgens and would improve the quality of life of patients.

SARMs also have a number of advantages over testosterone and AAS, as they exhibit tissue selectivity, which allows them to have poorly expressed or no androgenic effects, and at the same time to have similar or even more pronounced anabolic effects in comparison to testosterone and AAS. For example, selective modulators S-1 and S-4 do not decrease the plasma concentrations of FSH and LH in castrated rats, and have lower androgenic activity than testosterone propionate, but their anabolic effects are similar or even better than the ones thereof (Yin et al., 2003).

Of all selective androgen receptor modulators, Ostarine is the representative which is the most advanced in clinical trials. However, given that this group of substances is on the WADA prohibited list, SARM should not be used by athletes, even more so that a further in-depth research with the different representations of different ethnicities is needed.
tatives is required to clarify the mechanisms of their action, as well as any previously unreported side effects. Furthermore, there is lack of data regarding the interaction of SARMs with alcohol or drugs and their long-term effects.

SARMs are a new class of molecules which can contribute to the treatment process of various types of diseases. This is possible due to their very strong anabolic effect and weak androgenic one. They are also appropriate for increasing the physical working capacity and their use is prohibited in sports. This is the reason every sportsman whether professional or amateur should be familiar with them.

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The proposed papers are submitted to the Editorial Board of the Journal of Applied Sports Sciences. Article submissions should be only made through electronic submission module on. To submit a paper for publication in the journal, the submitting author should log in the ScholarOne Manuscripts platform. We kindly request authors to carefully read Instructions & Forms before submitting their articles for review. Once logged in, the author can see a chronology of submitted manuscripts and send a new one through “Start New Submission” => “Begin Submission”. The process of sending a new manuscript includes 7 basic steps:

Step 1: Select type of the manuscript, fill in the title and abstract in English language.
Step 2: File Upload. Here you may upload the Main Document, Title page, files with tables and figures. Remember, that the Main document should be anonymous. If you are submitting a revision, please include only the latest set of files. If you have updated a file, please delete the original version and upload the revised file.
Step 3: Attributes. Write and/or choose keywords. (The number of the keywords should not exceed 5 words).
Step 4: Authors & Institutions. Enter your co-authors’ information by searching on each of their email addresses below. If they have an existing account, their information can be easily imported to the submission. If necessary, you may add a co-author as a new user in the system by clicking “Create New Author”.
Step 5: Reviewers. To suggests a reviewer or request the exclusion of a reviewer, click the Add Reviewer button below and enter their information along with the desired designation.
Step 6: Details and Comments: The submitting author may enter or paste a cover letter text into the "Cover Letter" box. The cover letter may also be attached. Answer any remaining questions appropriately.

Step 7: Review & Submit. Review the information below for accuracy and make changes as needed. After reviewing the manuscript proofs at the foot of this page, you MUST CLICK 'SUBMIT' to complete your submission.

The received manuscripts are reviewed in accordance with Author’s Guidelines by a member of the Editorial Board. Manuscripts that do not comply with the requirements shall be returned to the authors for revision. Manuscripts that meet the requirements shall be admitted for review.

For each of the submitted and approved articles the Editorial Board shall assign minimum two reviewers. Reviews shall be made in terms defined by the Editorial Board and in accordance with its requirements to the reviewers.

Reviewing of articles shall be done in accordance with the standards for the evaluation of manuscripts through the double-blind peer review system. The reviewers give their assessment of the manuscripts in terms of the following criteria: scope of the research, novelty of the examined issues, originality, accuracy and clarity of the abstract describing the main text, logic structure and sequence of the submission, relevance of the methodology, validity of the results, proving the thesis, applicability of the results, validity of findings and conclusions, propriety and relevance of citations, accuracy and clarity of language.

The Editor-in-Chief commits the final decision for publication, based on the conclusions of the reviewers. The decision can be: publish it without revisions, publish it after revision in accordance with the recommendations made in reviews, refuse to publish. If the Editorial Board commits a decision to publish the manuscript after revision upon recommendations, authors should review and answer to the Editorial Board’s e-mails. The authors have to revise their manuscripts and present a report of the revisions they made in terms defined by the Editorial Board, upon which the Editorial Board commits a decision whether to publish it or refuse to publish the manuscript. If there are contradictions of the reviews, the Editorial Board may determine an additional reviewer (reviewers).

SUBMISSION AND STRUCTURE REQUIREMENTS OF THE ARTICLES

The article submissions shall be provided in Microsoft Word format, as follows:
Font: Times New Roman 12;
Format of the pages: Page Setup: Top: 2,5 cm, Bottom: 2,5 cm, Left: 2,5 cm, Right: 2,5 cm
Line Spacing: 1,5 lines; First Line: 1,5 cm; Paper Size: A4.
The main structure of the article shall include:
● First page; ● Introduction; ● Main text; ● Conclusions; ● References.

TITLE PAGE (PAGES)
The Title page/s includes:

Title of the article (it is recommended the title of the article be short (5-10 words) and present the main topic of the study);

Abstract. The abstract of the articles, whose main text is in Bulgarian language should be written in English. For publications that are all in English language, the abstract should only be in English language. It should be short and clear and concisely contain the following elements:
Introduction (“background” of the study) (required);
Purpose and objectives of the study (required);
Applied methodology (“staging of the research”) (required)
Achieved major results (required)
Leads (conclusions) (required);
Limitations of the research and consequences (if any)
Practical implications (if any); Originality/Value (required);
The maximum length of the abstract should not exceed 300 words.
**AUTHOR’S GUIDELINES**

**Keywords** (specify up to 5 keywords in English).

**Article Classification.** Authors must categorize their paper as part of the ScholarOne submission process. The category which most closely describes their paper should be selected from the list below:

- **Original Article/Research paper.** This category covers papers which report on any type of research undertaken by the author(s). The research may involve the construction or testing of a model or framework, action research, testing of data, market research or surveys, empirical, scientific or clinical research.
- **Reports.** These papers describe scientific research, presented on a scientific forum/conference.
- **Discussions/Conceptual paper.** These papers will not be based on research but will develop hypotheses. The papers are likely to be discursive and will cover philosophical discussions and comparative studies of others’ work and thinking.
- **Studies.** The papers covered by this category shall analyse actual and important issues, the study should be with high scientific value and proven practical value.
- **Editorial Materials/General review.** This category covers those papers which provide an overview or historical examination of some concept, technique or phenomenon. The papers are likely to be more descriptive or instructional (“how to” papers) than discursive.

**MAIN TEXT**

**Introduction**

The purpose of the introduction is to convince readers that the published research contains novelty and it is applicable. It answers the following questions:

- What is the main problem?
- Are there any existing solutions (indicates the level of study the problem at the moment)?
- What are the best solutions according to the author/s?
- What is the main limitation of the research?
- What is expected to be achieved by the author of the research?

The main text is structured into separate sections, distinguished by their titles (headings should be brief, with clear indication of the differences between their hierarchy). The preferred format for writing the main titles is to be bold format and subtitles to be written in italics. font – Times New Roman 12, capitals, left alignment).

The main text should include:

- **Purpose and objectives of the study.** The purpose and objectives of the study should ensure the understanding of the publication’s focus and should justify its structure. After that, authors should specify:
  - What is the significance of the publication?
  - Why the publication is important and original?
  - To whom is the publication designed?

  Additionally, can be discussed potential utility of practice, importance for future studies, detailed limitations of the study and others.

- **Main thesis and hypothesis of the research.** Authors’ arguments about their merit are presented.

- **Applied methodology and methods.** The author should indicate the main methods used by him in a separate title. Author should demonstrate that the methodology is robust and appropriate to achieve the objectives. It is expected by the author to focus on the main theme, to point the main stages of his research, to show the used methods and influences that determine the chosen approach by him, to give arguments why he has chosen specific examples and others.

- **Achieved major results.** When presenting the results, it is important that authors focus on the essentials. The publication must contain only the essential facts and those with a wider meaning, without giving many details of every possible statistics. If development is full of statistics, it is possible to prevail over the conclusions and after all the publication to be seen primarily as an enumeration of facts, not as a scientific study. The main thesis of the author must be clearly traceable and steadily established.

  When describing the results author should seek answers to the following questions:
  - Do you provide interpretation for each of the submitted results you want?
Are the results consistent with what other researchers have found?
Are there any differences? Why?
Are there any limitations?
Does the discussion logically lead the reader to your conclusion?

It is important when presenting the results not to make statements that go beyond what results can acknowledge.

**Conclusion**

The general rule is that the conclusion should not only contain a summary of the research (it can be found in the abstract). The conclusion should give answers to the set at the beginning of the publication questions and to indicate opportunities for further research. It would be better to reveal how the achieved results will be applied in practice and to identify constraints in this regard. While indicating how this research can be applied and extended in future studies, it is not accepted in the conclusion to introduce new material or state the obvious. In the conclusion it should be emphasized what is different in the research results, what stands out in the design or is unexpected.

**Notes**

Notes or Endnotes should be used only if absolutely necessary and must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.

**Funding agencies**

The funding agencies of the scientific research should be added in Step 6 of the submission process on ScholarOne system.

**Figures**

All Figures (charts, diagrams, line drawings, web pages/screenshots, and photographic images) should be submitted in electronic form.

All Figures should be of high quality, legible and numbered consecutively with Arabic numerals. Graphics may be supplied in colour to facilitate their appearance on the online database.

- If possible, the figures should be made in graphical programs (Corel Draw, Adobe Illustrator, Adobe PhotoShop) or Excel. The figures should not be in Picture format. They should be numbered consecutively in order of citation in the text. Numbers and titles of the figures are placed below them. Authors should avoid many inscriptions inside the figures.

- Pictures and scanned images can be made into separate files, preferably in JPG or TIFF format, not embedded in the text. Photos must be of good quality and suitable for printing. Colour illustrations are accepted in exceptional cases after special agreement and eventual additional costs!

- If authors make a blueprint they should use Word Equation. The numbers of formulas should be written in brackets in the left side of the page!

**Tables**

Tables should be typed in Word Table or Excel format. They should be numbered consecutively according to citation in the text. Each table should have a title. Numbers and titles of the tables are placed over them. It is preferable that it fit on the page without turning widest part of the sheet horizontally. The necessary explanations are given below by means of appropriate symbols / characters.

**References**

References to other publications must be in Harvard style and carefully checked for completeness, accuracy and consistency.

The cited authors should be presented in any of the following ways:

- Surname and year of publish (ex. Adams, 2006)
- Citing both names of two and year of publish (ex. Adams, Brown, 2006)
- When there are more than three authors, it is typed the surname of the first author and year of publish (ex. Adams et al., 2006)

At the end of the paper a reference list in alphabetical order should be supplied.
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