INFLUENCE OF TRAINING WITH INERTIAL LOAD ON ABILITY OF FORCE DEVELOPMENT AND MAXIMAL RUNNING VELOCITY

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Abstract
The aim of this research was, within the scope of training with appliance of additional inertial load, to generate changes in motor performance of maximal running velocity as well as to confirm in observed variables adaptive processes for which it is supposed that they significantly influence on maximal running velocity. The experiment with parallel groups was realized whereby the acting of experimental factor (inertial load) was in two levels. The first, control group K realized the designed sprint training freely, in other words it did not apply additional load. The second, experimental group E-R ran with load fasten on their hands, and the third experimental group E-N with the load on their legs. The research contains initial and final measurement variables of acceleration and maximal running velocity (VTF1 i VTF2) in running at maximal sprint of 50m. Also, variables force and normalized force were observed -coefficient force extensor in knee-joint (k-EKOL), coefficient of heels force-(k-PFST), level of force extensor in knee-joint reached in 100 milliseconds (F_100ms-EKOL), level force of flexors reached in 100ms (F_100ms-PFST), extendors in knee-joint (EKOL/r), heels flexors (PFST/r). The applied training treatment is on the level of statistical significance(p<0.05), influenced on force development of applicant, because small load was applied with maximal velocity performance. It came to significant change in level of velocity of force development variables extensor of knee (k-EKOL) and heels flexors (F_100ms-PFST) within the group with load on legs E-N and control group K. Simultaneously, in each group is significantly enlarged force of extensors and flexors. Velocity of running increased with E-R in the phase of acceleration. Due to connection of maximal running velocity and force variables through force influence, it can be possible to influence on maximal running velocity. Using experimental factor in training for force development with small loads and maximal running velocity, increased the level of force and the result of such work is increased force in areas of lower loads during higher velocity performance. The variables of muscle force can be seen as a predictor when maximal running velocity is in question since there is connection with running velocity. The domination of maximal force variables in phase of acceleration is shown, while the influence of velocity of force development variables (RFD) remains disputable in maximal running velocity phase.

Key words: INERTIAL LOAD / MAXIMAL RUNNING VELOCITY / VELOCITY OF FORCE DEVELOPMENT / NORMALIZED ISOMETRIC FORCE
INTRODUCTION

The influence of specific training conditions on running kinematics and dynamics is considered particularly interesting problem for researchers and coaches. From that point, quantitative and qualitative changes of certain kinematic and dynamic variables, caused in the course of training by application of external factors, especially inertial load are particularly interesting. There is not a sufficient number of studies, so this paper uses paradigms and conclusions of the following researches.

When examining connection of motor space variables with the performances of running at maximal velocity, certain disagreement appears. It is considered that they resulted from structural, neutral and mechanical differences in muscle expression between dynamic and isometric testing of force and strength, as well as from the way of testing of variables in the sense of application of their absolute and/or normalized value. Certain studies have shown significant correlation between some factors of strength and velocity (Mero et al., 1981; Alexander, 1989 and Mero, 1985, according to Young et al., 1995), while others report low or insignificant connection (Berg et al., 1986 and Farrar & Thorland, 1987). It is presumed that this expressed discrepancy resulted from researches on different samples according to gender, age and competitive level. It is also considered that specificity of expression of force in sprint can influence the result. The aforesaid researchers, who determined an insignificant connection between running velocity and force, performed tests in conditions of isometric and/or concentric contractions, but contrary to that, great number of researchers showed significant connection by observing eccentric contraction and/or a cycle extension – contraction of muscles (SSC).

The investigation of connection of running velocity with maximal isometric force demonstrated different results:

This connection is pointed in the papers of Wilson (1996), who found a correlation of maximal isometric force of knee extensors with running velocity (r= .62) and Mero (1981), with 30-meter running (r= .62). Young et al. (1995) determined that between maximal isometric force and running velocity there is higher correlation than between maximal isometric force and starting velocity in the course of initial acceleration phase. The best individual predictor of maximal velocity was force normalized by body mass (BM), generated 100ms after the start, whereas the correlation was (r= .80). Increase of force in the course of 100 ms showed the highest correlation with running velocity. That measure of force was chosen because it was proved that an average contact time when running at maximal speed was 101ms in males (average time in males at 100m was 10.62s) and 108 ms in females (average time in female subjects at 100m was 12.22s).

When estimating relation of velocity and maximal force, Young et al., (1995) established high correlation (r= -.79, p<.03), whereas the normalized force (F/tm) with running velocity showed considerably lower correlation (r= -.26, p<0.05). Correlation between maximal force and starting velocity (time at 2.5 m) was not significant on the level p<0.05, (r= -.72, p<0.07) as well as the correlation (r= -.44) between starting velocity and normalized force (according to body mass). These results point out to interconnection of maximal (absolute) force with velocity, which was not the case with the normalized force. Similar findings are recorded in the research of Mero et al., (1992) referring to the opinion that normalized and absolute force are not significant for starting velocity.

Contrary to the above stated, certain researches pointed to low correlations between running velocity and maximal isometric force. Thus, Wilson (1995), for 30-meter running found correlation (r= .08), Considine et al. according to Wilson (1996), also determined low correlation (r= -.19 do r= .36) between maximal isometric force and running speed (acceleration) at 5 and 10 meters. Hakkinen (1987) determined significant connection between isometric force and standing high jump (r=.81) and half-squat high jump (r=.80), while he was examining force of knee extensors (18 male and female basketball players).

The importance of time pattern of force expression for sprinter performance was still not fully clarified. In majority of researches dynamic tests for assessment of force showed significant connection with maximal velocity and acceleration in running at maximal velocity. Young et al. (1995) determined that 16 out of 27 measures of force correlated with starting ability. The greatest correlation being for maximal dynamic force (MDS), normalized according to body mass, which was (r=.86).

The explanation for this correlation could be in the specific nature of this force measure with regard to starting acceleration. The procedure of jump testing required that MDS be performed at angle of 120°, which was similar to the angle of 126°, which corresponds to the position of a leg when blocking.
The tests of standing high jump showed the following correlation with maximal running speed \( r=0.68 \), Mero & Callister, according to Abernethy, 1995; \( r= .77 \), Young et al., 1995). Some other studies also (Mero et al., 1981; Tharp et al. and Costill., according Young et al., 1995) showed significant correlations between running speed and measures of vertical push-off. In the research Young et al. (1995) determined that a jump from a certain height - drop jump (DJ) produced a relatively small flexion in the knee-joint and short contact time (163ms) in the 60-centimeter jump. Mero (1985) reported a significant correlation \( r=.72 \) between 50 centimeters high (DJ) and maximal velocity.

Normalized force, realized in a series of jumps during 15s showed high correlation \( r=.79 \), Young et al., 1995). Very high correlations were recorded between running velocity at 60-meter and mechanical force, assessed by dynamic test of a series of high jumps in 15s, amounting to \( r=.84 \) according Young et al., (1995); and \( r=.70 \) as stated by Mero and Callister (accordind Abernethy, 1995). Lower correlations were noted between high jump and force value expressed for the first 350ms of isometric contraction of knee extensor (Baker, 1994), which does not surprise having into consideration the previous results, as well as in younger subjects (14 years of age) between sprint at 30 meters and a series of jumps for 60s \( (r=.56) \).

According to the presented results it could be concluded that **dynamic tests enable relatively more reliable results on abilities derived in dynamic conditions**, than isometric tests, which can be supported by the fact that while performing isometric and dynamic tests, muscular activities are realized under influence of different neuromuscular mechanisms. Dynamic tests (jumps, running at maximal velocity) are characterized by feedback regimen of muscular work based on usage of energy of elastic deformation. The tests of individual high jumps, or a series of jumps measure not only force of chemical processes, but also mechanical energy from elastic elements of connective-muscular system.

Based on the aforesaid, it would be possible to make pragmatic issues whose solving would contribute even more to resolving of the treated problems. One should also examine quality and quantity of connection between muscular strength and motion features at maximal running speed, as well as the connection of tests for assessment of velocity of force development and maximal isometric force.

In that sense, besides the maximal isometric force \( (F_{max}) \), at the recorded signal of change of force in time, the variables for estimation of velocity of force development are also identified. The most frequent test of velocity of force development is assessment of force development increase (RFD\(^3\)) calculated as a maximum of the first derivative of time function of force (Matavulj, 1998; Wilson & Murphy, 1996), or as an incline of the curve at the given moment compared to the beginning of force development (Aagaard et al., 2002).

Other tests are also used for assessment of velocity of force development. The most frequently applied criterion is the size of intervals between two achieved force levels\(^2\), for example \((T_{10%-90%})\), and they are determined relatively with regard to maximal isometric force (Slievert & Wenger, 1994, according to Pajić, 2006). Certain authors, however, suggest that velocity of force development is determined by time needed to reach certain force level with regard to zero level (Wilson & Murphy, 1996), or by achieved force level at the assigned time moment (Izquierdo et al., 1999), which was implemented in this research when assessing the achieved force level in the 100th millisecond.

When applying an inertial load, firstly, there is a change of inertia momentum, and therefore the adaptation of motion kinematics of the loaded extremities. Whereby the decisive role belongs to the control of elements of neuromuscular system, in the sense of increase of muscular work, manifested, first of all in time pattern of intensity of force and strength (Martin & Cavanagh, 1990; Nilsson & Thorstensson, 1987).

Gravitational force is an important factor and to the great extent determines the conduct of muscles and functional adaptation. Some researches showed fast adaptation (several days) even to forces that are not gravitational (Lackner, 1981; Lackner & Graybiel, 1982 according Bosco et al., 1986).

In the already mentioned experiment (Evans et al., 1983), in which running was carried out on a treadmill with additional load, by monitoring EMG activity, greater manifested force was determined than when working without an additional load.

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1) RFD (rate of force development) – coefficient of explosivity determined as a maximum of the first derivative of time function of force.

2) Level of increase of force at isometric muscular action (Cavagna, 1988), reaches the highest value between 0.15s and 0.25s (Stone et al., 2001), which corresponds approximately to one third of maximal velocity of muscular contraction.
Influence of Training with Inertional Load on Ability of Force Development and Maximal Running Velocity


The performance of squat jump and production of mechanical force in the course of 15s of jumping are in high correlation with the percentage of fibers of fast jerks in vastus lateralis. Therefore, it is completely reasonable to presume that the increase of activation of phase motor units took place in the conditions of additional load (Bosco et al., 1986).

As stated by Bosco et al., (1986) three weeks after regular intensive training with additional load, the control group did not manifest any changes in a single assessed mechanical variable (p<0.05). On the other hand, (F-v) relation of the experimental group shifted after exercising to the right. Significant shift of (F-v) curve to the right clearly demonstrates that exercising with additional load efficiently modified mechanical work of leg muscles in the experimental group athletes. The progress was homogenous and statistically significant (p<0.05-0.001) in all curve parts.

In their research (Nilsson & Thorstensson, 1987) noted the increases in the average generated mechanical force in 15s jumps (p<0.05) and in jumps from height (p<0.05). There were also, no statistically significant differences between pre-test and post-test results (∆h) for (SMJ) squat push-off and landing.

When running at maximal speed with additional load, the mechanism of feedback regimen of muscular work is affected. It is assumed that optimal additional load applied as training means could significantly contribute to improvement of abilities of force development, provided that it does not affect negatively running kinematics.

Further studying of the effects of application of additional load as training stimulus could be significant from both practical and theoretical aspect, and the basic problem could be in the research of adaptive processes which directly resulted from its application. The detailed studying of the role of additional load would enable their more efficient usage as potential training stimulus for development of maximal running velocity.

Application of external load while running at maximal speed has already been suggested as potential training method (Stefanović, 1979; Bosco et al., 1986; Allemeyer et al., 1994, according to Pajic, 2006). Such training of running at maximal speed with additional load (Delecluse et al., 1995) should be efficient in order to enable conversion of enlarged muscular force in muscular strength (Sleivert et al., 1995).

There is no doubt that certain variables of force development affect with one part the ability of running velocity. The share of these mechanisms is more indirect because running is complex activity that depends on many other abilities (techniques, morphology of the body...). It is supposed that for this reason there are different results in the level of correlation of variables of isometric tests and sprinters’ abilities. Based on the afore explained it is more important to monitor the way in which certain mechanisms (ability of force development velocity) change under the influence of training which keeps the basic kinematic running pattern, than to monitor the level of correlation between the variables of isometric tests and running velocity.

Two basic presumption in this research are that: (1) the assigned inertial load in training of running velocity development would significantly affect improvement of abilities of force development and velocity of force development of knee extensors and plantar flexors; (2) the assigned inertial load in training of running velocity development would significantly affect development of abilities of acceleration and maximal running speed.

METHODS

Sample of subjects

The sample of this research consisted of students of the Faculty of Sport and Physical Education in Belgrade (Table 1). The sample of students was defined from actual population (n=18). At the time of research the students were healthy and without injuries of locomotor apparatus. With regard to initial sprint time the subjects were classified in three groups depending on running velocity. The groups were formed attempting to make equal distribution of abilities in them. The subjects confirmed formal written consent prior to their participation in the research.
result of multiplication of mass and allometric parameter\(^4\) according to the formula:

\[ F(r) = \frac{F_{\text{max}}}{m^b} \]

Where:
- \( F(r) \) – is normalized value of maximal force;
- \( F_{\text{max}} \) – maximal isometric force;
- \( m \) – body mass;
- \( b \) – allometric parameter.

Since the body dimensions are factors which influence the results of the muscular force tests, normalization of muscular force with regard to body dimensions was realized in order to eliminate their impeding influence.

### Measurement and variables

From the motor area of the subjects the variables of force and velocity of force development were measured in the experiment but of those muscular groups presumed to contribute significantly with their activities to manifestation of maximal running velocity.

### Force variables

Measurement of all force variables was realized by electronic dynamometer SPREBAR IF-5 consisting of measuring transformer (probe) and amplifier with display, compatible with multi-channel analogous-digital converter -1401 plus (Cambridge Electronics Device - CED) and by application of SIGAVG software. The acquisition of results and the curve were realized by applicative software SPIKE2 for Windows version 3.10. The recorded signal represented time function of the realized maximal isometric force.

### Evaluation of normalized isometric force \( F(r) \)

The evaluation of normalized isometric force \( F(r) \) was realized by application of allometric method\(^3\) by division of maximal isometric force with the

\[ F(r) = \frac{F_{\text{max}}}{m^b} \]

Since the body dimensions are factors which influence the results of the muscular force tests, normalization of muscular force with regard to body dimensions was realized in order to eliminate their impeding influence.

### The following force variables were measured:

- knee-joint extensors (EKOL)
- plantar feet flexors (PFST)

### Evaluation of force development velocity (force momentum)

The ability of muscles to develop force (or force momentum)\(^5\) by appropriate velocity was identified from the recorded time function of the force signal. Measurement was carried out on ankle plantar flexors (PFST) and in knee-joint extensors (EKOL).

\[^4\] The presented literature review recommends application of allometric method where muscular strength was noted either as muscular force or as muscular moment of force. The recommended method on normalization should provide more reliable results such that can be compared to the results of other studies.

\[^5\] When estimating neuromuscular function, it is significant to appraise velocity of force development since the time necessary to develop an adequate force level in certain sports events is a determining efficiency factor (Wilson & Marphy 1996).
Influence of Training with Inertional Load on Ability of Force Development and Maximal Running Velocity


Force increase (RFD)\(^6\) or the coefficient of explosivity is calculated as relation of maximal force and time necessary for its realization i.e.:

\[
(k) \text{ or } (RFD) = \frac{F_{\text{max}}}{t_{\text{max}}}
\]

Whereby:
\(F_{\text{max}}\) – is maximal reached force;
\(t_{\text{max}}\) – time in which maximal force is realized (difference from the start of MVC till the moment of reached maximal force).

The following variables were measured:
- coefficient of increase of force in knee joint extensors - \((k) - \text{EKOL})\)
- coefficient of increase of force of plantar feet flexors - \((k) - \text{PFST})\)

Since the average duration of the contact with the surface in sprint lasts approximately 100ms, the identified force intensity was reached in 100 ms \((F_{100ms})\) from the beginning of contraction.

The measured variables were:
- level of force of knee-joint extensors achieved in 100 milliseconds \((F_{100ms} - \text{EKOL})\)
- level of force of plantar flexors achieved in 100 milliseconds \((F_{100ms} - \text{PFST})\)

Experiment protocol

The experiment was realized in parallel groups with the action of the experimental factor (inertial load) occurred in two levels. The first, control group K realized the prescribed sprint training, freely, i.e. without an application of additional load. The second, experimental group E-R ran with an additional load attached to their arms. The third experimental group E-N ran with an additional load attached to their legs.

Experimental factor

In order to increase inertia momentum of legs and arms in the training procedure, an additional load was applied in the form of cuffs with plates, fixed to ankles and wrists. In compliance with the previous researches and the achieved results (Ropret et al., 1998; Stegemann, 1981) a load of 1.8kg was applied, for which it was calculated that it modifies rotation inertia moment on average for around 50%.

Testing procedure

The research encompassed initial and final measurement of all variables. Both measurement were realized in two days whereas the initial measurement (pretest) was carried out one day before the beginning of implementation of training procedure, and the final one was two days upon completion of the training procedure. Measurement of dynamic and kinematic variables was realized while running at maximal velocity at 50-meter track. Each subject ran twice, and better result was used for final elaboration (lower total time). Measuring devices (photocells - Brower timing system) were placed at the start, so that they registered standing start \((0.5m)\), then after 25m, and finally at 50m. That way, during one running the appropriate kinematic variables were recorded within the phase of acceleration \((0 \rightarrow 25m)\) and the phase of maximal velocity \((25m \rightarrow 50m)\). The values were measured with accuracy of 0,01s.

Training procedure

Each subject had a warm-up before training with application of sprinter (jog, high knee lifting, grabbing step, skip – half-skip running etc.), followed by dynamic extension of important muscular groups engaged in sprint. This was followed by a set of acceleration with changes of running rhythm. After the warm-up, the athletes carried out their special training procedures. During a six-week experiment, trainings were held 3 times a week. The training intensity grew progressively and volume of work was increased every two weeks. In the first two weeks each subject carried out a set of five repetitions of his/her own specific training regimen. In the third and fourth week training load was increased to two sets each of five repetitions. In the last two weeks the intensity of training was increased to three sets of five repetitions for each group. One set consisted of five repetitions, and maximal running velocity was 50m, from semi-high start, with 2-3min. of resting between each running, with 8-10m of recovery between sets.

\(^6\) RFD - rate of force development – is determined as the maximum of the first derivative of the recorded force signal in time (Haff et al., 1997; Wilson & Marphy 1996), or as a curve incline at given moment compared to beginning of force development (Aagaard et al., 2002).
Acquisition of experimental results

From descriptive statistical indexes, we implemented measures of central tendency (arithmetic mean), as well as the measure of dispersion – standard deviation). Out of methods of qualitative statistical analysis, a statistical procedure of **T-test for dependent samples** was applied:

The level of significance of (p<0.05) was applied to determine significance of differences between pre-test and post-test for each group. The results were elaborated by application of applicative statistical program SPSS (12.0)

**RESULTS**

The average values of motor variables of **velocity of force development, normalized maximal isometric force**, as well as times achieved in the phases of acceleration and maximal running speed at **initial and final** measuring, were presented in the tables 2, 3 and 4, as well as in graphs 1-4.

Table 2. Average values of motor variables **velocity of force development, normalized maximal isometric force**, as well as times achieved in phases of acceleration and maximal running velocity at **initial and final** measurement for control group K.

<table>
<thead>
<tr>
<th>Pair</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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<td>Pair 8</td>
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<td>.13755</td>
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Influence of Training with Inertional Load on Ability of Force Development and Maximal Running Velocity

Table 3. Average values of motor variables velocity of force development, normalized maximal isometric force, as well as times achieved in phases of acceleration and maximal running velocity at initial and final measurement for experimental group E-R.

<table>
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<tr>
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<th>Std. Error Mean</th>
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<td>0,09683</td>
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Table 4. Average values of motor variables velocity of force development, normalized maximal isometric force, as well as times achieved in phases of acceleration and maximal running velocity at initial and final measurement for experimental group E-N.

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<tr>
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<td>2</td>
<td>I-k-PFST</td>
<td>353,1150</td>
<td>6</td>
<td>37,71878</td>
<td>15,39863</td>
</tr>
<tr>
<td></td>
<td>F-k-PFST</td>
<td>349,8767</td>
<td>6</td>
<td>125,14594</td>
<td>51,09061</td>
</tr>
<tr>
<td>3</td>
<td>I-F100ms EKOL</td>
<td>101,2083</td>
<td>6</td>
<td>26,76096</td>
<td>10,92512</td>
</tr>
<tr>
<td></td>
<td>F-F100ms EKOL</td>
<td>118,3867</td>
<td>6</td>
<td>15,15506</td>
<td>6,18703</td>
</tr>
<tr>
<td>4</td>
<td>I-F100ms PFST</td>
<td>137,2233</td>
<td>6</td>
<td>44,19212</td>
<td>18,04136</td>
</tr>
<tr>
<td></td>
<td>F-F100ms PFST</td>
<td>197,7767</td>
<td>6</td>
<td>46,91093</td>
<td>19,15131</td>
</tr>
<tr>
<td>5</td>
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<td>6</td>
<td>9,98882</td>
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</tr>
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<td></td>
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</tr>
<tr>
<td>6</td>
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<td>5,54168</td>
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</tr>
<tr>
<td></td>
<td>F-PFST</td>
<td>85,7150</td>
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<td>6,40330</td>
<td>2,61414</td>
</tr>
<tr>
<td>7</td>
<td>I-VTF1</td>
<td>3,8033</td>
<td>6</td>
<td>0,11021</td>
<td>0,04499</td>
</tr>
<tr>
<td></td>
<td>F-VTF1</td>
<td>3,9417</td>
<td>6</td>
<td>0,38186</td>
<td>0,15589</td>
</tr>
<tr>
<td>8</td>
<td>I-VTF2</td>
<td>3,0067</td>
<td>6</td>
<td>0,14320</td>
<td>0,05846</td>
</tr>
<tr>
<td></td>
<td>F-VTF2</td>
<td>3,1633</td>
<td>6</td>
<td>0,44603</td>
<td>0,18209</td>
</tr>
</tbody>
</table>
Graph 1. Results of initial and final measurement for variables coefficient of force increase of knee joint extensors - \( (k - EKOL) \) and coefficient of force increase of plantar feet flexors - \( (k - PFST) \) for control group, experimental group E-R and experimental group E-N.

Graph 2. Results of initial and final measurement for variables force level of knee joint extensors achieved in 100 milliseconds \( (F_{100ms} - EKOL) \) and force level of plantar flexors achieved in 100 milliseconds \( (F_{100ms} - PFST) \) for control group, experimental group E-R and experimental group E-N.
Graph 3. Results of initial and final measurement for variables force of knee joint extensors (EKOL) and plantar feet flexors (PFST) for control group, experimental group E-R and experimental group E--N

Graph 4. Results of initial and final measurement for variables running time in acceleration phase (VTF1) and running time in maximal velocity phase (VTF2) for control group, experimental group E-R and experimental group E--N
Statistical significance of the measured variables *velocity of force development*, *normalized maximal isometric force*, as well as times achieved in the phases of acceleration and maximal running speed at *initial and final measurement*, including pre test and post test, arithmetic means and standard deviation was shown in tables 5, 6 and 7.

**Table 5.** Results of T-test for motor variables *velocity of force development* and *normalized maximal isometric force* and times achieved in acceleration phases and maximal running velocity at *initial and final* measurement for control group K.

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>1-k-EKOL - F-k-EKOL</td>
<td>-111,47667</td>
<td>100,3298</td>
<td>40,95948</td>
<td>-2,722</td>
<td>5</td>
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<tr>
<td>Pair 2</td>
<td>1-k-PFST - F-k-PFST</td>
<td>-1,07833</td>
<td>92,32834</td>
<td>37,69289</td>
<td>-.029</td>
<td>5</td>
</tr>
<tr>
<td>Pair 3</td>
<td>I-F100ms EKOL – F-F100ms EKOL</td>
<td>-4,22333</td>
<td>10,09679</td>
<td>4,12200</td>
<td>-1,025</td>
<td>5</td>
</tr>
<tr>
<td>Pair 4</td>
<td>I-F100ms PFST – F-F100ms PFST</td>
<td>-59,07667</td>
<td>54,59522</td>
<td>22,28840</td>
<td>-2,651</td>
<td>5</td>
</tr>
<tr>
<td>Pair 5</td>
<td>I-EKOL - F-EKOL</td>
<td>-1,92667</td>
<td>1,16156</td>
<td>.47421</td>
<td>-4,063</td>
<td>5</td>
</tr>
<tr>
<td>Pair 6</td>
<td>I-PFST - F-PFST</td>
<td>-8,77000</td>
<td>6,07357</td>
<td>2,47953</td>
<td>-3,537</td>
<td>5</td>
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<tr>
<td>Pair 7</td>
<td>I-VTF1 – F-VTF1</td>
<td>.05167</td>
<td>.09152</td>
<td>.03736</td>
<td>1,383</td>
<td>5</td>
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<tr>
<td>Pair 8</td>
<td>I-VTF2 – F-VTF2</td>
<td>-.04167</td>
<td>.10458</td>
<td>.04269</td>
<td>-.976</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 6.** Results of T-test for motor variables *velocity of force development* and *normalized maximal isometric force* and times achieved in acceleration phases and maximal running velocity at *initial and final* measurement for experimental group E-R.

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>1-k-EKOL - F-k-EKOL</td>
<td>-41,94333</td>
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<td>5</td>
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<td>Pair 2</td>
<td>I-k-PFST - F-k-PFST</td>
<td>-46,48667</td>
<td>68,81481</td>
<td>28,09353</td>
<td>-1,655</td>
<td>5</td>
</tr>
<tr>
<td>Pair 3</td>
<td>I-F100ms EKOL – F-F100ms EKOL</td>
<td>-13,15333</td>
<td>20,28482</td>
<td>8,28124</td>
<td>-1,588</td>
<td>5</td>
</tr>
<tr>
<td>Pair 4</td>
<td>I-F100ms PFST – F-F100ms PFST</td>
<td>-36,66500</td>
<td>55,48087</td>
<td>22,64997</td>
<td>-1,619</td>
<td>5</td>
</tr>
<tr>
<td>Pair 5</td>
<td>I-EKOL - F-EKOL</td>
<td>-3,40333</td>
<td>1,86402</td>
<td>.76098</td>
<td>-4,472</td>
<td>5</td>
</tr>
<tr>
<td>Pair 6</td>
<td>I-PFST - F-PFST</td>
<td>-9,98167</td>
<td>5,23457</td>
<td>2,13700</td>
<td>-4,671</td>
<td>5</td>
</tr>
<tr>
<td>Pair 7</td>
<td>I-VTF1 – F-VTF1</td>
<td>.03000</td>
<td>.02280</td>
<td>.00931</td>
<td>3,223</td>
<td>5</td>
</tr>
<tr>
<td>Pair 8</td>
<td>I-VTF2 – F-VTF2</td>
<td>.00167</td>
<td>.09806</td>
<td>.04003</td>
<td>.042</td>
<td>5</td>
</tr>
</tbody>
</table>
Influence of Training with Inertional Load on Ability of Force Development and Maximal Running Velocity


The results of the statistical analysis of the control group K, indicate that affected by experimental factor, improvements were achieved in variables (k-EKOL, p<.042, F_{100ms} PFST, p<.045, EKOL, p<.010, PFST, p<.017).

The results of the statistical analysis of the experimental group E-N indicate that affected by experimental factor, improvements were achieved in variables (k-EKOL, p<.010, F_{100ms} PFST, p<.016, EKOL, p<.000, PFST, p<.000).

The results show that changes in control group K and in the experimental group E-N have the same tendency, although that is not the case if we compare changes in absolute values. It was expectable that the group carrying a load on their legs would have greater increase in variables of force when compared to control group. Significant changes in the same variables of force in the control group K when compared to the experimental E-N can be explained by excessive sensitivity of the sample of subjects, their familiarization with the tests, since for realization of the experiment, we chose students who were not training actively. At the same time in these groups, there were no statistically significant changes in maximal running speed in both phases. In control group, in the phase of acceleration there was a certain improvement of velocity (0.052с), but not on the level of statistical significance, and overall running time in both phases was not improved. That could be explained by the fact that intensity and volume of the load for this group were very small, and conditioned by the intensity and volume of load of the experimental groups which at that same treatment (number of sets, number of repetition in a set), carried additional load.

It is noticeable that in the experimental group E-N there was reduction in running velocity in both phases (VTF1 – from 3.803 to 3.941, and VTF2 – from 3.006 to 3.163) but, although not statistically significant, it can be considered from the aspect of sports practice, that deceleration of running in both phases is significant. The reasons for velocity drop in the experimental group E-N could lie in the presumption that the applied load caused inadequate adaptation of the neural system in managing of the motions i.e. change of kinematics pattern of leg movement. That would mean that there was violation of technique, i.e. of coordination of movements.

DISCUSSION

In this research we analyzed changes of some motor variables, assumed to significantly influence manifestation of maximal running velocity, as a consequence of application of programmed training procedure with additional load on distal parts of arms and legs.

The results of the statistical analysis of the control group K, indicate that affected by experimental factor, improvements were achieved in variables (k-EKOL, p<.042, F_{100ms} PFST, p<.045, EKOL, p<.010, PFST, p<.017).

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| Table 7. Results of T-test for motor variables velocity of force development and normalized maximal isometric force and times achieved in acceleration phases and maximal running velocity at initial and final measurement for experimental group E-N. |
|---|---|---|---|---|---|
| **Paired Differences** | **Mean** | **Std. Deviation** | **Std. Error Mean** | **t** | **df** | **Sig. (2-tailed)** |
| Pair 1 | I-k-EKOL - F-k-EKOL | -133,45 | 80,59586 | 32,90312 | -4,056 | 5 | .010 |
| Pair 2 | I-k-PFST - F-k-PFST | 3,23833 | 111,0695 | 45,34394 | .071 | 5 | .946 |
| Pair 3 | I-F100ms EKOL – F-F100ms EKOL | -17,1783 | 24,28619 | 9,91480 | -1,733 | 5 | .144 |
| Pair 4 | I-F100ms PFST – F-F100ms PFST | -60,5533 | 41,83375 | 17,07855 | -3,546 | 5 | .016 |
| Pair 5 | I-EKOL - F-EKOL | -5,28167 | 1,30389 | 53231 | -9,922 | 5 | .000 |
| Pair 6 | I-PFST - F-PFST | -16,8533 | 4,11114 | 1,67837 | -10,04 | 5 | .000 |
| Pair 7 | I-VTF1 – F-VTF1 | -.13833 | .34055 | .13903 | -.995 | 5 | .365 |
| Pair 8 | I-VTF2 – F-VTF2 | -.15667 | .35517 | .14500 | -1,080 | 5 | .329 |

In this research we analyzed changes of some motor variables, assumed to significantly influence manifestation of maximal running velocity, as a consequence of application of programmed training procedure with additional load on distal parts of arms and legs. The results of the statistical analysis of the control group K, indicate that affected by experimental factor, improvements were achieved in variables (k-EKOL, p<.042, F_{100ms} PFST, p<.045, EKOL, p<.010, PFST, p<.017).

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Stegman (1981) established that a leg behaves as a pendulum whose frequency depends on its inertial features. Since the inertial features of lower extremities were significantly modified in this experiment, the subjects adapted to new optimal frequency and step length (Bobbert et al., 1986, according to Pajic, 2006). The said authors explained that insufficient velocity of a leg in swing, since loaded with inertial load, can be a limiting factor for further increase of running velocity. The assumption that these changes result from the adaptation of nervous system to managing of the movements aimed at creation of the most economic movement structure (frequency – step length) for each type of load in the conditions of attempt of maintaining constant velocity. The adaptation, among other things, due to changed inertial conditions for legs, occurs in the extension of swing phase, which together causes decrease of step frequency. If the velocity is the same, or in slight decline any reduction of frequency results in extension of steps.

The second reason for velocity drop in the experimental group E-N could be a deficit in velocity (reactive) force that is necessary in the modified conditions of overcoming gravitational forces, forces of surface reaction, as well as of intention of lower extremities. Although there was a statistically significant increase in the results of variables (k-EKOL, p<.010, F100mс PFST, p<.016, EKOL, p<.000, PFST, p<.000), the assumption is that an overall effect of adaptation to newly created conditions was not sufficient and that maybe duration of experimental treatment can be a limiting factor.

The adaptation in the mentioned conditions is of neurogenous and miogenous nature (Thornton & Rummel, 1974; Milner-Brown et al., 1975; Moritani & De Vries, 1979 according to Bosco et al, 1986; Bosco et al., 1984; Rusko & Bosco, 1987). Firstly, the neural factors adapt relatively fast by increasing the number of recruited motor units, by increased level of discharge and their better mutual work synchronization. However, the second phase (miogenous adaptations) is featured by increase of their glycolitic potential and can last a few months (McDonagh and Davies, 1984, according Bosco et al., 1984). That justifiably points out to necessity of special discharge of the length of duration of the experimental treatment and can possibly raise doubt about the length of the prepared treatment in this research, with regard to different plasticity of certain examined variables, as well as the specificity of the experimental factor.

The results of the statistical analysis of the experimental group E-R indicate that a statistically significant improvement of the results in variables (EKOL, p<.007, PFST, p<.005). occurred by action of the experimental factor. In this experimental group there was a statistical change in running velocity in acceleration phase (VTF1, p<.023).

The explanation for this could be in the fact that adaptations of arm movements to modified conditions of inertia momentum, and thus gravitational forces, is much greater when compared to the legs. They happen because of aspiration to keep the intensity of movement, so a reduction of an angle upper arm – forearm, in order to eliminate action of force on the longer branch, i.e. reduction of rotation moment, which causes increase of frequency. The increased arm frequency, whereby with regard to the body. Left leg an right arm move ventrally, and the other two extremities dorsally and vice versa, provokes an elevated level of neural activities (reciprocal inhibition) and thus positively influences kinematics of legs. Having in mind that the reductions of amplitude of movements are more possible by flexion in elbow joint than in knee and hip joints (Maidell & Alexander, 1991) it can be presumed that such adaptive processes, as consequences of arms loading, can influence change of legs kinematics. It is assumed that there was adding of positive effects of carrying arms load with simultaneous insignificant change of the basic pattern of motion kinematics of legs, which probably positively affected the overall neuro-muscular adaptation (Pajic, 2006). In this group, affected by the experimental treatment there was a statistically significant increase of variables of maximal force of knee-joint extensors (EKOL, p<.007) and of plantar flexors (PFST, p<.005), which can be linked to running velocity increase in the phase of acceleration. It is known that force generated in muscles is greater, if the time of contractions is longer, because certain time is required to reach tension of the muscular contractile components. In the course of acceleration phase, when contact time of each step is around 200ms, greater part of capacity of muscular force can be used. At maximal running speed (surface contact time around 100ms) only a small portion of muscular force can be manifested during each contact with surface (Alabin & Uchkevich, 1976, according to Pajic, 2006), so that superiority of measurements of variables of maximal force is greater in the accel-
The reasons for quantity and quality of the above described adaptation, when applying this specific experimental factor could be in the following statements.

It has already been suggested that additional load causes increased muscular activity (Martin, 1985), increase of gravitational forces (Rusko & Bosco, 1987), as well as increased reaction of the surface during the phase of push-off (Frederich & Hagy, 1986). When running with additional load, due to interaction of forces of inertial load with force of gravitation (Rusko & Bosco, 1987), velocity of foot lowering during the preparation phase of push-off phase are greater, and therefore also the forces generated during eccentric muscular contraction. Consequently, the reached inertial concentric force of plantar flexors is greater, and therefore the executed subsequent work is greater.

Increase of force influenced by application of additional loads, causes also increased muscle firmness, creating thus conditions for more efficient usage of cycles of extension-contraction while going form the eccentric into the concentric phase. This increased efficiency can be created since firmer muscle is more resistant to stretching that is caused during to the eccentric phase. Muscle firmness can also help in coupling time between eccentric and concentric muscular contractions. The greater the firmness, the greater ability of muscles to endure great load. This can lead to shorter contact time with surface, greater force production during contact time with surface and therefore to greater running velocity.

It can be assumed that application of additional loads can influence efficiency of functioning of a cycle extension-contraction (SSC), and thus positive effects of exercising in the feedback work regimen are additionally increased, and especially because the velocity of eccentric muscular contraction is greater. The consequence of velocity increase of muscular contraction is shortening of time generation of the reached force level.

The aforesaid activities caused moving of (F-t) relation to the left, increase of explosive force (RFD), and therefore also raising of the level of manifestation of legs reactive force. The graph (F-t) relation identifies that by shifting of the curve force-time to the left and by shortening of time needed to generate force of equal intensity, more than by increasing its intensity and/or by shifting upwards by increase of intensity of generated force for the same time, based on greater intensity of generating maximal force, more than by shortening time and/or by combination of both of them. It is assumed, due to the nature of the experimental factor and therefore adequate training, that moving of the curve force-time to the left in this research are more the result of the shortening of time for force generation, that of the intensity of force generation. The moving of the curve shows that exercising with additional load modified mechanical work of legs, during the contact with surface, increased force production and velocity of its development, and therefore also increase of the reactive force, which again caused shortening of the contact phase. Such relations were reported by Maidell and Alexander (1991), and determined by monitoring of EMG activities (Evans et al., 1983).

It is assumed that the applied load on arms and legs in experimental groups presumed increased use of fast muscular fibers, more significant activation of glycolytic potential, as well as increased nervous impulsion towards active muscles (Holland, 1984; Mero et al., 1987; Tinning & Davis, 1978). It should be noted that efficiency of the said changes depends also on structure of muscular fibers of the subjects. Since running is at maximal velocity, “fast” individuals when compared to the “slow” ones, show better performances in velocity of force development after the training procedure, and therefore also in reactive force because running actually represents a series of reactive jumps. The aforesaid differences can be explained by differences in length of duration of junction of transfersal bridge of myofilaments of myosin and actine during muscular contraction. Slow fibers are characterized by longer duration of this junction, with regard to fast fibers, so that slow fibers show better usage of energy of elastic deformation while carrying out slower amortizing movements, and vice versa, fast fibers show better usage when carrying out reactive movements (Bosco et al., 1983).

From the aforesaid it could be concluded that training for force development could move the curve force-time to the left only to the limit determined by the capacity for increase of the impulse from CNS through alfa motor neurons. Then, it is necessary to reintroduce the training of maximal strength. Evidently by applying of this experimental training procedure (strength training with inertial load) one can
influence moving of the curve force-time to the left only by shortening the time of strength generation (Pajic, 2006).

Since the level of force increase rises even when compared to capacity for generating of maximal force, from the aspect of force increase, it is essential to know which is the level of maximal force to start with in the strength training. In other words, since force is function of strength, it is necessary first, by applying adequate training procedure, to “build up” the curve force-time, and then to shift it to the left. Wherby you cannot develop maximal force by simply, constantly increasing the load up to a certain value, and then concentrate to development of strength (Hakkinen, 1991, according to Bompa, 1999). The solution is successive replacing of phases of development of maximal force and strength, conditioned by periodisation of training and physiological laws of adaptation processes of neuro-muscular system to appropriate training conditions.

It is well known that the increase of level of force rise from the aspect of capacity for generation of maximal force, exercises are carried out by maximal voluntary activation of muscular fibers against great (even up to supra maximal) loads. The velocity of execution of such motor tasks is small and/or equal to zero, but the velocity of neuromuscular activation is maximal, so that the level of force growth is increased. However, even such increased level of force growth, isolated for itself is unfitting, so this method can be used only in combination with another method, more appropriate for specific requests of manifestation of reactive force in motor tasks, in its motion structure similar to those requested by the given event. In this case it is running at maximal velocity, and method is force development by small inertial loads. The method of force development with small loads and maximal velocity of execution, increases the level of force growth, and the result of such work is increased force in the zone of lower loads, at higher speed of execution. Since it increases the level of force growth exactly in the time interval of duration of contact in the phase of push-off, it can be a useful method of force development in running at maximal velocity, but again only in combination with other methods, in order to compensate shortages in generation of higher intensity force.

Thus, the above statements proved that the experimental training procedure requires also successive application of training for force development from the aspect of exploiting of capacity for generation of maximal force, since it is always more suitable to apply the selected training of reactive force at higher initial level of maximal force. That way, the applied experimental procedure would have better efficiency from the aspect of greater influence of maximal force and strength on kinematics and dynamic variables of maximal running velocity.

CONCLUSIONS

Force and strength variables cannot completely and with great sensitivity describe technically extremely complex activity as running at maximal velocity is.

Since, the students who do not train actively are chosen for realization of the experiment (excessive susceptibility of sample), there was not an expected improvement of running velocity, except in the phase of acceleration in the experimental group E-R. This indicates that such applications of inertial load without prior individualization, (normalization when compared to mass and height of the subjects) cause suspicion about the justification of their application for development of maximal running velocity. This particularly refers to legs load, whose function is much more complex because they generate propulsive impulses and perform swings. From the athletic practice it is well known that minimal influences can cause great changes in running speed (type or brand of footwear, surface etc.).

Application of inertial load positively affected force parameters and in that sense it could be applied in training practice. Increase of force of selected muscular groups could be realized by regular dozing and adequate positioning and consequently it could have a feedback influence the increase of running velocity.

According the aforesaid assertion on connection of maximal running velocity and some parameters of force it can be concluded that through influence on strength one can also influence maximal running velocity.

That causes shifting of (F-v) relation of experimental groups to the right and of (F-t) relation to the left. Shifting of the curves (F-v, F-t) shows that

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7) It is well known that testesterone level rises in the first six to eight weeks of training for development of maximal force, and then decreases gradually (Hakkinen, 1991, according to Bompa 1999). The researches indicate that training with constant load of high intensity can reduce resistance of bone tissue.
exercising with additional load modified mechanical work of leg muscles, increased force production during contact time with surface, which influenced certain increase of explosive force.

It can be ascertained that application of additional load further increases the positive effects of exercising in feedback work regimen, especially due to greater velocity of eccentric muscular contraction. They represent efficient means intensifying effects of training in feedback work regimen. By their application you influence the efficiency of functioning of the cycle extension-contraction (SSC), and thus the possibility of its application in realization of reactive force. The intensity of stretching of active muscle in eccentric muscular contraction is increased by applied additional load. That intensified muscle stiffness and provokes activity of the reflex of stretching, which increases velocity of eccentric muscular contraction as well as production of initial force of concentric phase. The increased velocity of muscular contraction causes shortening of time of generation of the achieved force level.

It can be assumed that the applied training treatment at development of velocity (reactive) force of the subjects, because small load was applied with maximal execution velocity. That increased the level of force growth and therefore of strength as well, in the zone of small loads at great velocities of execution. The level of force growth occurs exactly in the time interval of duration of surface contact, so this method of force development can be useful for improvement of running at maximal velocity, but only in combination with other methods which would compensate for defects in generating force of higher intensity.

Based on the obtained results there was a significant change in the level of variable velocity of force development of knee extensors in the group with leg load and of variable plantar foot flexors in the group with arm load. It is assumed that, having in mind features of the experimental treatment, influence was made on moving of the curve force-time (F-t) to the left, only by shortening of time of force generation without influence on force development for the aspect of capacity for generation of maximal force, so successive shifting of phases of maximal force and strength is suggested.

Since body dimensions are factor which influences the results of the test of muscular force, the applied normalization of muscular strength related to body dimensions is important in order to eliminate their impeding influence.

For achieving efficiency necessary in maximal running velocity in the phase of supporting, vertical moving of body center of gravity (generated during fall in the phase of flight), as well as horizontal velocity in decrease (created due to stopping in the phase of supporting), must be optimized. For fulfillment of those requests of efficiency, force production must be maximized, because it will limit flexion in the phase of supporting, creating thus conditions for usage of reactive force from eccentric to the concentric phase. Therefore, a minimal flexion in the hip, knee joints and ankle is requested during contact with surface at any step.

The training applied in this paper, affected knee extensors i.e. increase of knee resistance to flexion (increase of efficiency in the isometric work regimen), as well as the ability of plantar flexors to increase velocity extension-flexion (efficiency of the feedback work regimen), for greater mechanical limitation on the vertical axis, and primarily for greater stabilization of movement of hip joint. That causes smaller lowering of body center of gravity, its shorter path and therefore greater body velocity. Additionally, by blocking flexion in knee joint, conditions are created for establishment of optimal values of the critical angle of body inclining, which is vital for neutralization of negative influence of the horizontal component of force of reaction of surface in dorsal direction, as well as of favoring of influence of that component in ventral direction. Thus slowing down of bodies are significantly neutralized at every step contributing at the same time to its greater velocity.

It is assumed that the described changes resulted mainly from adaptation of nervous system to managing of movements aimed at creation of the most economic movement structure (frequency before all) for each type of load in conditions of keeping the constant velocity. The adaptation occurs by dozing of the intensity of force and strength, thus by change of the moment of quantity of movement and moment of inertia segment, by control of action of the components of forces of reaction, gravitational force, as well as by coordinating the work of kinetic chains through activities on single-ankle and double-ankle muscles when matching velocities and simultaneous pairing of movements.
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Influence of Training with Inertional Load on Ability of Force Development and Maximal Running Velocity


Zoran Pajic, PhD, Assistant for General Anthropomotorics
University of Belgrade, Faculty of Sport and Physical Education
Blagoja Parovica 156, Belgrade, PhD
e-mail: zoran.pajic@dif.bg.ac.rs.rs

Duško Ilić, PhD, Associate prof. For Biomechanics and Motor control
University of Belgrade, Faculty of Sport and Physical Education
Blagoja Parovica 156, Belgrade, PhD
e-mail: dusko.ilić@dif.bg.ac.rs.rs

Vladimir Mrđaković, Assistant for Biomechanics
University of Belgrade, Faculty of Sport and Physical Education
Blagoja Parovica 156, Belgrade, PhD
e-mail: vladimir.mrdakovic@dif.bg.ac.rs.rs

Nenad Janković, PhD, Assistant for Athletics
University of Belgrade, Faculty of Sport and Physical Education
Blagoja Parovica 156, Belgrade, PhD
e-mail: nenad.jankovic@dif.bg.ac.rs.rs

Željko Rajković MA, assistant researcher
e-mail: zeljko.rajkovic@ub2009.org