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Structure of Application of Inertial Functional Loads on Kinematic and Dynamic Running Performance in the Phase of Maximum Speed

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Abstract: The aim of this research was to induce changes in the kinematic and dynamic performance of running at maximum speed within the training with the application of additional inertial load, as well as to determine the adaptation processes in the observed variables that are supposed to significantly affect the maximum running speed. The research included initial and final measurement of all variables. Both measurements were performed in two days, the initial measurement (pretest) one day before the start of the training procedure, and finally two days after the end of the training procedure. Measurement of dynamic and kinematic variants was realized when running at maximum speed on the track from the 25th to the 50th meter. Each respondent ran twice, and a better score was used for the final treatment. Measuring devices (photocells - Brower timing system) are placed at the start, so that they register the start from the place (0.5m), at 25m and finally at 50m. Values were measured with an accuracy of 0.01s. The change of kinematic variables recorded by non - contact telemetry measurement (two - dimensional system) of one step cycle during the sprint step in the phase of maximum running speed, and as a consequence of applying a programmed training procedure with additional load at two different locations, was analyzed. The obtained results indicate that the applied experimental factor within a specific six-week period caused statistically significant changes in the experimental (ER) and (EN) groups.

Keywords: Velocity of Running, Stride Frequency, Stride Length

1. Introduction

It can be assumed that the kinematic and dynamic variables of running change at maximum speed under the influence of additional load depending on its weight and the place of its fixation. Different results have been obtained on this, and they are probably a consequence of the application of different methodologies in research. This involved the application of different load sizes, places of their fixation as well as different running speeds at which the experiments were conducted. However, in most studies, measurements were performed at moderate speed and treadmill, with the exception of some where the change in kinematic variables under conditions of maximum speed and acceleration with additional load was analyzed [11]. Results indicating an increase in frequency and a decrease in stride length have been obtained in most papers [19]. The opposite results, when the frequency is reduced and the stride length is increased, have been reported in studies [20, 21, 23] etc. The result, when the increase in the load on the arms and especially the legs caused a decrease in the running speed, while the stride length remained unchanged and the frequency decreased, was obtained [18]. In some studies, the results did not show any change in stride length and frequency [3, 4, 12]. In research Majdell and Alexander [11] verified changes in the kinematics of running at a maximum speed of 40 m, under the influence of training with the additional load. In the experiment, treatment of six weeks of training with an additional load (10 pounds, 4.5 kg) was applied. The treatment had the effect of statistically significantly increasing the maximum running speed (from 5.16 ms-1 to 5.26), shortening the contact phase (from 0.13 to 0.11 sec), statistically significantly reducing the angle of the reflex leg at the moment of reflection (from 4.27 to 4.12 work) as and to increase the angle of maximum flexion of the lower leg (from 2.62 to 3.28 rad). The application of the external load of the subjects when running at maximum speed has already been suggested as a potential training method [2, 17, 18]. This maximum speed running training with additional load should be effective to enable the conversion of increased muscle strength into muscle strength [6, 18].

This research aims to examine the effects of the application of additional inertial load in the training process on the maximum running speed. The applied experimental factor should have caused changes in the kinematic and dynamic performance of running at maximum speed to determine the adaptation processes in the observed variables.

Table 1. *Descriptive indicators for respondents of each group.*

Variables	AS for each group ± SD (N = 6)		
	K	ER	EN
Age (years)	20.8 ± 1.8	20.2 ± 1.12	20.4 ± 1.7
Height (cm)	176.3 ± 9.0	177.8 ± 11.2	178.4 ± 8.12
Weight (kg)	69.36 ± 11.7	72.7 ± 7.8	71.4 ± 8.5
50m - time (s)	6.83 ± 0.24	6.63 ± 0.65	6.81 ± 0.44

K - control group; (ER) - exp. group with load on the arms;
EN - exp. a group with a load on the legs.

2. Methods

2.1. Sample of Respondents (Participants)

The sample of respondents in this study consisted of students of the Faculty of Sports and Physical Education in Belgrade (Table 1). A sample of students from the current population was defined (n = 18). Concerning the initial sprint time, the subjects were classified into three groups depending on the running speed. The groups were formed trying to make an equal distribution of abilities in them.

2.2. Measurement Conditions and Variables (Instruments)

A system of three pairs of photocells - the Brower timing system - was used to measure the time parameters.

Variables were measured:

1) running speed in the maximum speed phase (BT);
2) average step length in the maximum speed phase (DK);
3) step frequency in maximum speed phase (FK).

To measure the number of steps (BK), a system of three video cameras was used, one of which recorded a section of 25-50m to determine the number of steps between the first and last contact, and the first and last contact were identified with the other two cameras. stride length (DK) was calculated by dividing the distance between the first and last foot contact by the number of steps. Step frequency (FC) was calculated by dividing the running speed by the step length. Based on the time for which the section was run, the maximum running speed (BT) was calculated.

MacReflex 3.2 Measurement System with Macintosh Software version 3.0 (for 2D and 3D systems) was used to measure kinematic parameters. The measurement procedure with this system provides non-contact (telemetric) motion measurements. The basic principle of the system is to record the positions of a certain number of well-defined points in space. The measured points are marked with reflective markers, and their movements are registered with a special video camera (Figure 1).

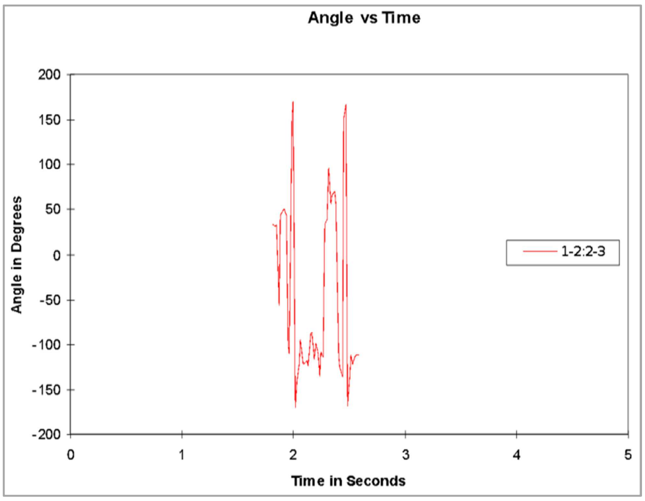

Figure 1. *Display of realized angles in the elbow joint in time (between the first and second and second and third reflective markers on the hand, when performing the maximum running speed, obtained by non-contact (telemetry) motion measurement, using the MacReflex system.*

Kinematic variables measured on the track at maximum running speed:

1) angle in the center of the knee joint at the time of rebound (UKTO);
2) angle in the center of the knee joint at the time of contact (UKTK);
3) the angle of maximum flexion of the lower leg during the last swing (UMFN);
4) the angle of maximum forearm flexion during the last swing (UMFR).

Based on the previous measurement and software acquisition of data using the application software MacReflex 3D.V.3.1B2 and adaptable Microsoft Excel software, the values of variables (UKTO, UMFN, UMFR, UKTK) were determined.

2.3. Experimental Protocol

An experiment with parallel groups was performed, where the effect of the experimental factor (inertial load) was in two levels. The first, control group (K) realized sprint training without applying additional load. The second, experimental group (ER) ran with an additional load attached to the arms. The third, experimental group (EN) ran with an additional load attached to the legs.

2.4. Experimental Factor

To increase the moment of inertia of the legs and arms in the training procedure, an additional load was applied in the form of cuffs with plates, fixed to the ankle and wrist. Following previous research and the results achieved [3, 4, 18, 20], a load of 1.8 kg was applied, which was calculated to change on average. torque of inertia by about 50%.

2.5. Testing Procedure

The research included the initial and final measurement of all variables. Both measurements were realized in two days, the initial measurement (pretest) one day before the start of the training procedure, and finally two days after the end of the training procedure. The measurement of dynamic and kinematic variables was realized when running at the maximum speed on the track from the 25th to the 50th meter. Each respondent ran twice, and a better result was used for the final processing. Measuring devices (photocells - Brower timing system) are placed at the start so that they register the start from the place (0.5m), at 25m, and finally at 50m. Values were measured with an accuracy of 0.01 s.

2.6. Training Procedure

After warming up, the athletes performed their special training procedures. During the six-week experiment, training was performed 3 times a week. The intensity of training increased progressively, and the volume of work increased after every two weeks. In the first two weeks, each subject performed one series of five repetitions of their specific training regimen. During the third and fourth weeks, the training load was increased to two sets, and in the last two weeks to three sets of five repetitions. The run was performed at a maximum speed of 50m from a semi-high start with 2-3min. rest between each run and with 8-10 min. recovery between series.

2.7. Data Analysis (Acquisition of Experimental Results)

Among the descriptive statistical indicators, measures of central tendency (arithmetic means - AS) as well as measures of dispersion (standard deviation - SD) were applied. From the method of qualitative statistical analysis, the t-test for dependent samples was applied. A significance level of ($p < 0.05$) was applied to determine the significance of the differences between the pre-test and the post-test for each group. Statistical analysis was performed in the statistical program SPSS 16.

3. Results and Discussion

The results of descriptive statistics for all three groups on the initial and final measurements are shown in Table 2.

Table 2. *Descriptive statistics on initial and final measurement for the control group (K), experimental (ER), and experimental (EN) group.*

variable	measurement	control (K)		experiment. (ER)		experiment. (EN)	
		M	SD	M	SD	M	SD
BT	final	8.11	, 45	8.45	, 27	8.29	, 30
	initial	8.10	, 35	8.45	, 35	8.33	, 37
DK	final	2.01	, 12	2.16	, 14	1.98	, 23
	initial	1.96	, 20	2.08	, 14	1.88	, 24
FK	final	4.02	, 20	3.92	, 24	4.22	, 46
	initial	4.19	, 27	4.07	, 29	4.47	, 47
UKTO	final	160.83	4.66	166.16	1.16	161.00	1.41
	initial	160.66	4.63	160.33	1.03	162.66	1.03
UKTK	final	158.33	3.50	164.00	2.09	155.33	1.75
	initial	156.83	4.87	157.00	2.28	159.00	1.09
UMFN	final	38.83	2.85	43.00	3.63	45.66	3.72
	initial	39.66	2.33	42.16	4.87	42.50	4.08
UMFR	final	104.83	3.48	97.50	3.78	113.16	4.21
	initial	106.33	3.72	106.33	4.50	106.00	6.09

The results of the t-test for small dependent samples on the initial and final measurements are shown in Table 3.

The applied training procedure in the maximum speed phase did not cause statistically significant changes in running speed (BT) in any group. From the above, it can be seen that the examinees of the group (EN) reduced their running speed, but not within the statistical significance. Comparison of the results from the initial and final measurements showed that in the control group there were no statistically significant changes in the observed variables.

In the experimental groups, there are statistically significant differences in the variable's average step length (DK) and that - the respondents had a lower score on the initial (ER - $p < .022$) and (EN - $p < .003$) and variables of step frequencies.) - respondents on average had a higher score on the initial (ER - $p < .002$) and (EN - $p < .000$). So, there was an extension of the step and a decrease in its frequency.

Table 3. *T-test for small dependent samples on initial and final measurement for the control group (K), experimental (ER), and experimental (EN) group.*

variables	control (K)			experiment. (ER)			experiment. (EN)		
	t	df	Sig. (2-tailed)	t	df	Sig. (2-tailed)	t	df	Sig. (2-tailed)
BT	-, 874	5	, 422	-, 015	5	, 988	-, 626	5	, 559
DK	1,270	5	, 260	3,272	5	, 022	5,423	5	, 003
FK	-1,572	5	, 177	-5,890	5	, 002	-7,998	5	, 000
UKTO	, 415	5	, 695	10,750	5	, 000	-2,712	5	, 042
UKTK	1,307	5	, 248	8,573	5	, 000	-8,696	5	, 000
UMFN	-1,746	5	, 141	1,185	5	, 289	10,304	5	, 000
UMFR	-2,423	5	, 060	-22,007	5	, 000	3,909	5	, 011

If you run at speeds that approach the values of $7 m.s^{-1}$, the speed increases at the expense of increasing the length of the steps, provided that the frequency does not change significantly [8]. The mentioned speed represents the entrance to the upper limit zone for maximum stride extension because when the running speed exceeds $7 m.s^{-1}$, the stride length starts to grow more slowly, while at a speed of $8\text{-}9 m.s^{-1}$ it reaches a maximum. Further increase in speed is achieved based on increasing the frequency of steps, which continues to grow faster because only at the expense of its increase, the maximum running speed is reached [8, 9, 11, 14, 16, 22]. The subjects reached a maximum speed of $8\text{-}9 m.s^{-1}$, and thus a stride length. Since there are no statistically significant changes in running speed (BT) in any group, it can be assumed that the cause is a statistically significantly increased stride length, and thus a reduced number of steps, ie a reduced frequency of steps on the run section, especially in groups (K) and (EN). The decrease in frequency was most likely due to the increased moment of inertia of the leg, and thus to the decrease in the angular velocity of the segment.

The reasons for the speed drop in the experimental group (EN) could be in the assumption that the applied load caused *inadequate adaptation of the nervous system in* movement management, ie. that there was a violation of technique, ie coordination of movements. Another reason could be a deficit *in speed (reactive) power* which is required in the changed conditions of overcoming the gravitational forces, the reaction forces of the substrate, as well as the inertia of the lower extremities.

According to Stegman (1981), an increased moment of inertia results in a lower natural frequency for the leg acting as a pendulum. This indicates that the length of the swing phase increases and the step frequency decreases. Assuming that the speed of movement is unchanged, a decrease in the frequency of the steps is accompanied by an increase in the length of the steps. This claim was also proved by Martin (1985) in an experiment in which he applied a load of 1 kg to the foot, which increased the moment of inertia by 13%. In this experiment, the inertial properties of the legs were significantly modified, the subjects did ″reluctantly″ adjusted to the new optimal step frequency. Bobbert et al., (1986) presented that insufficient speed of the leg, since it is loaded with inertial load, in the swing can be that limiting factor for further increase of running speed.

It is assumed that these changes are the consequences of adjusting the nervous system in the control of movements to create the most economical structure of movement (frequency x stride length) for each type of load in an attempt to maintain a constant speed. Adaptation, among other things, due to the changed inertial conditions for the legs, takes place in the prolongation of the swinging (resting) phase, which also causes a decrease in the frequency of steps. If the speed is the same or is slightly decreasing, any decrease in frequency results in an extension of the stride. It can be assumed that with the prolongation of the duration of the influence of the training factor, there would be a correction in the manifestation of speed strength, and consequently an easier correction of the changed inertial conditions for the loaded leg. That would cause better adaptation. more efficient realization of movements in changed conditions of overcoming gravitational forces, the inertia of legs, and reaction forces of the ground, and thus a relative increase in movement frequency. This would probably increase the running speed. Based on the presented results, it is possible to emphasize the greater importance of frequency than stride length when running at maximum speed, which agrees with the findings of many authors [1, 7, 15-18].

This investigation C. B. Cooke et al., (1991) examines the effects of vertical and horizontal loading on the O2 intake (VO2) response of children (n = 8) and adults (n = 8) to treadmill running. In unloaded running, the children required a significantly greater VO2 (P less than 0.001) than the adults [mean difference 7 ml.kg-1.min-1 (18.5%)]. There was no significant difference in the VO2 response of the children and the adults to either vertical or horizontal loading [5].

It was concluded that in supramaximal effort it is possible to run at a higher stride rate than in maximal running. Data suggest that supramaximal sprinting can be beneficial in preparing for competition and as an additional stimulus for the neuromuscular system during training. This may result in adaptation of the neuromuscular system to a higher performance level [13].

Applied training procedure in the phase of maximum speed code experimental groups (ER) and (EN) caused statistically significant changes in the variable angle in the center of the knee joint at the time of rebound (UKTO) - subjects initially had a lower score on average (ER - $p < .000$) and a higher score (EN - $p < .042$). For a higher running speed at the moment of reflection, it is very important to have a higher critical angle of inclination of the body during reflection, ie a higher angle in the knee joint during reflection (UKTO), ie. less flexion, because the more positive the influence of the horizontal component of the force of the action of the substrate on the running speed in the ventral direction. It follows that the lowering of the center of gravity causes greater flexion in the knee joint (UKTO), a smaller critical angle of inclination of the body, and a less positive effect of the horizontal reaction force of the substrate in the ventral direction. The results indicate that the increase in the angle at (ER) had a positive effect,

Applied training procedure experimental groups (ER) and (EN) caused statistically significant changes in the variable angle in the center of the knee joint at the time of contact (UKTK) - subjects had a lower score on average (ER - p < .000) and a higher score on the initial (EN - p < .000). During the run, when landing at the moment of contact with the ground (UKTK), a certain horizontal deceleration occurs, ie. extinguishing the speed of the center of gravity of the body, ie the depreciation phase is realized. For a higher running speed at the moment of contact with the ground, it is very important to have a lower critical angle of inclination of the body during contact, ie a higher angle in the knee joint during contact (UKTK), ie. less flexion, because this reduces the negative impact of the horizontal component of the ground reaction force on the running speed in the dorsal direction. The results indicate that the increase in the angle at (ER) had a positive effect,

From the above results, it can be seen that the subjects in the experimental group (EN) increased the average angle of maximal flexion of the lower leg during the last swing (UMFN) within the statistical significance - the subjects had a lower score on the initial (EN - p < .000). This change harms the running speed, since the moment of inertia of the foot increases, the angular speed decreases, and thus the frequency of the foot.

The angle of maximum flexion of the forearm during the last swing (UMFR) changed significantly - the subjects had a higher score (ER - p < .000) and a lower score (EN - p < .011) on average at the initial measurement. Since a smaller angle reduces the moment of inertia of the hand, its higher speed is achieved, ie a shorter duration of the swing phase of the hand. This increases the frequency of movement of the body segment, ie a positive effect on a higher running speed. Interestingly, despite the above, the experimental group (EN) significantly increased the average angle of maximal forearm flexion during the last swing (UMFR) within statistical significance. It could be expected that the subjects would adapt to the changed inertial conditions and perform adequate flexion in the elbow joint, reducing the angle and moment of inertia. However, due to a significant increase in the angle of flexion of the leg in the swing phase, and thus the moment of inertia, probably due to synchronized work of the collateral extremities, increasing the positional moment of inertia of the arm is a compensatory attempt to counter increased forces of inertia moving in the opposite direction. This, therefore, could affect better synchronization of the movement of the contralateral segments, with the aim of a more stable overall movement of the lever system of the whole body. The increased frequency of the arms that counter the legs causes an increased level of neural activity (reciprocal inhibition) and thus affects the kinematics of the legs. Given that reductions in swing amplitude are possible in the elbow joint than in the knee and hip joint [11], it can be assumed that such adaptation processes, as a consequence of the load on the hands,

The results of descriptive statistics for all three groups in the final measurement are shown in Table 4.

Table 4. *Descriptive statistics for all three groups of respondents at the final measurement.*

variables	control (K)		experiment. (ER)		experiment. (EN)	
	M	SD	M	SD	M	SD
BT	8.11	0.45	8.45	0.27	8.29	0.30
DK	2.01	0.12	2.16	0.14	1.98	0.23
FK	4.02	0.20	3.92	0.24	4.22	0.46
UKTO	160.83	4.66	166.16	1.16	161.00	1.41
UKTK	158.33	3.50	164.00	2.09	155.33	1.75
UMFN	38.83	2.85	43.00	3.63	45.66	3.72
UMFR	104.83	3.48	97.50	3.78	113.16	4.21

A comparison of the final measurement results for all three groups in all variables is shown in Table 5.

Table 5. *T-test for small independent samples between all three groups on the final measurement.*

	K-ER			K-EN			ER-EN		
	t	df	Sig. (2-tailed)	t	df	Sig. (2-tailed)	t	df	Sig. (2-tailed)
BT	-1,590	10	, 143	-,805	10	, 439	,983	10	, 349
DK	-1,856	10	, 093	, 290	10	, 778	1,580	10	, 145
FK	, 758	10	, 466	-,953	10	, 363	-1,390	10	, 195
UKTO	-2,716	10	, 022	-,084	10	, 935	6,897	10	, 000
UKTK	-3,400	10	, 007	1,877	10	, 090	7,769	10	, 000
UMFN	-2,208	10	, 052	-3,566	10	, 005	-1,256	10	, 238
UMFR	3,492	10	, 006	-3,731	10	, 004	-6,777	10	, 000

There are statistically significant differences between the control group (K) and the experimental group (ER) and the experimental group (EN) on the following variables:

1) angle in the center of the knee joint at the time of rebound (UKTO) - subjects in the control group (K) had a lower score on average compared to subjects in the

group (ER) - ($p < .022$), and subjects in the group (EN) were on average had a lower score compared to the subjects of the group (ER) - ($p < .000$).
2) angle in the center of the knee joint at the time of contact (UKTK) - subjects in the control group (K) had a lower score on average compared to subjects in the group (ER) - ($p < .007$), and subjects in the group (EN) on average had a lower score compared to group (ER) athletes - ($p < .000$).
3) the angle of maximum flexion of the lower leg in the period of the last swing (UMFN) - subjects in the control group (K) had a lower score on average compared to subjects in the group (EN) - ($p < .005$).
4) the angle of maximum forearm flexion during the last swing (UMFR) - subjects in the control group (K) had on average a higher score compared to the subjects of the group (ER) - ($p < .006$) and a lower score compared to the subjects of the group (EN) - ($p < .004$), the examinees of the group (EN) had on average a higher score with the examinees of the group (ER) - ($p < .000$).

It is evident that the key differences between the groups are on the last variable (UMFR) and that this is where the effect of the experiment came to the fore. Also, the (ER) group is characterized by results on the variables angle at the center of the knee joint at the time of rebound (UKTO) and the angle at the center of the knee joint at the time of contact (UKTK), since this group differs significantly from the other two. The (EN) group is characterized by the angle of maximum flexion of the lower leg in the period of the last swing (UMFR), but only concerning the control (K).

4. Conclusion

The change of kinematic variables recorded by non - contact telemetry measurement (two - dimensional system) of one step cycle during the sprint step in the phase of maximum running speed, and as a consequence of applying a programmed training procedure with additional load at two different locations, was analyzed. The obtained results indicate that the applied experimental factor within a specific six-week period caused statistically significant changes in the experimental (ER) and (EN) groups. It is obvious that the different location of the inertial load in the experimental groups affects the changes of the observed variables differently, as well as that the applied additional load selectively affects the change of the observed variables. The applied load significantly influenced the kinematic variables whose obvious influence is on the favoring factors,

The results of this study open up some new dilemmas. It is not clear, whether the same load for the arms and legs is adequate, given that the adaptation of the arms to the changed conditions of the moment of inertia, and thus the gravitational forces, is much greater than in the legs, and whether the complete adaptation of arms and legs requires different time. In this research, there is a current attempt to increase the momentum of the amount of motion by changing the inertial conditions. The moment of momentum cannot be improved by the increased moment of inertia that is created when applying even a very small additional load (even when it is only a few hundred grams), and especially if it is applied at the end of the kinetic chain, because in that case inadequate high angular velocities. Introduction of the absolute value of the load without calculating it according to the actual mass of each locomotor system separately, raises suspicion because the moment of inertia itself increases by mr2, ie. the value of the introduced load is multiplied by the square, even if it is only one gram. Quadratic changes cause errors to multiply.

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