

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

PARAMETRI FUNKCIONALNIH SPOSOBNOSTI U TRČANJU – PREGLEDNO ISTRAŽIVANJE

Radosav Đukić¹, Goran Bošnjak², Vladimir Jakovljević² & Gorana Tešanović²

¹*Spartamedic, Austria*

²*University of Banja Luka, Faculty of physical education and sport, Bosnia And Herzegovina*

REVIEW SCIENTIFIC PAPER

doi: 10.5550/sgia.201601.en.dbjt

UDC: 796.422.012.1

Received: 26.05.2020.

Approved: 23.11.2020.

Sportlogia 2020, 16 (1), 1-30.

E-ISSN 1986-6119

Correspondance: Radosav Đukić, PhD.

Spartamedic, Vienna, Austria

Tel.: +43 664 1330916 E-mail: rade.djukic@chello.at

ABSTRACT

Running as an athletic discipline requires a high level of endurance and speed endurance, which is directly related to the cardiovascular and respiratory systems, ie the ability of an athlete's body to withstand loads, and the following are listed as relevant factors for running success: anaerobic strength and maximum O₂ consumption, lactic acid concentration and oxygen deficiency, ability to withstand stress, high ability to concentrate and its retention over longer periods of time. There is a lot of research that has studied the parameters of functional abilities in an attempt to find the most effective way to improve them, and since there are many similar and different data on this topic, this paper has been done to classify the available papers by domestic and foreign authors which would lead to conclusions applicable both in practice and for further research

For the purposes of this research, original scientific papers have been analyzed that dealt with functional abilities as success factors in short, middle and long distance running and the impact of training on functional abilities, found in electronic databases - Medline, PubMed, Researchgate, Web of Science and Google Scholar. The research used in this review monitored transversely the values of submaximal and maximal oxygen consumption, energy systems, heart rate values, pulmonary ventilation, blood lactate concentration, as well as their changes after longitudinal implementation of experimental protocols and training processes. Since the collected research had too few respondents from different populations with a small number of elite runners, and they did not have enough information about many years of experience, level of sports form, race categories, and descriptions of training and methods, obtaining empirical information based on evidence was limited, as well as reaching valid conclusions. Accordingly, there is a need for a more systematic approach to research and implementation of complex studies with a sufficient number of runners of all ages, both sexes of the elite level, and cooperation of academic

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

researchers, clubs and athletes to enable studies that would provide significant statistics, analysis and interpretation. The results identified in this review provide a starting point for future research that identifies and quantifies predictors of functional performance as factors of short, middle, and long distance running success.

Keywords: maximum oxygen consumption, lactate concentration, short distances, middle distances, long distances, training process

INTRODUCTION

Relevant factors stated for success in running on middle distances are: anaerobic strength and maximum VO_2 , lactic acid concentration and lack of oxygen, ability to withstand stress, high ability to concentrate and its retention over longer period of time, and as maximum consumption oxygen (VO_{2max}), which an athlete can achieve is not the only main determinant at endurance effort, but a significant role is played by a possible level at which maximum aerobic capacity can be used, many studies also state that an untrained beginner can raise his VO_{2max} 15-20% in just 12-16 weeks of regular and proper training (Frajtnic, 2012). Aerobic endurance can be improved by increasing oxygen uptake by increasing the ability to assimilate, transfer and use oxygen and by raising the anaerobic threshold to be able to run at higher speeds without entering the anaerobic zone, but it should be borne in

mind that the role of aerobic and anaerobic capacity and anaerobic energy sources in running depends on the intensity and duration of running (Skof, Kropej & Milic, 2002), and the quality of performance and success depend on the amount and structure of training load in a certain period of time.

Improving oxygen uptake by increasing the ability to assimilate, transfer and use oxygen is best achieved by a continuous load method, while raising the anaerobic threshold resulting in the ability to run at higher speeds without entering the anaerobic zone is best achieved by a repetitive load method (Coh, 1992). Also, different body structures are essential for young athletes during selection (Malousaris, Bergeles, Barzouka, Bayios, Nassis, & Koskolou, 2008), which are crucial for improving skills in many sports (Carter & Heath, 1990), and to assess the structure of

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

the whole body and its individual components it is necessary to identify anthropometric characteristics (McArdle & Katch, 1991). In boys at puberty there are rapid changes in the body, along with the accelerated growth of the skeleton muscle mass increases, which is the main reason for increasing maximum oxygen intake and improving endurance (which was low in the initiation phase) and athletic achievement (Idrizovic, 2013).

Anaerobic endurance research has also been addressed (Bowerman et al. 1999), as well as statements that anaerobic endurance can also be improved in two ways: by improving the ability to tolerate high levels of lactic acid which will allow continued activity and training of the neuromuscular system at a pace of racing and by improving anaerobic capacity of cells by increasing the amount of energy stored in the ATP of muscle cells. Aerobic endurance in one of its phases reaches stagnation, although the training process is carried out, so the goal in this phase (the phase of shaping athletes) should be - by applying endurance training to increase aerobic and anaerobic endurance, ie. bring any increase in endurance, which occurred during

prepuberty, to a higher level (Bompa, 2006). Also, it was found that (Rotstein, Dofan, Bar & Tenenbaum, 1986) nine-week interval training, in athletes, had a positive effect on anaerobic threshold, anaerobic capacity and aerobic power and led to an increase in anaerobic capacity (VO_2max). It was shown that two types of interval training - focused on lactate and ventilatory threshold led to an increase in VO_2max by 5% and 6%, in lactate threshold by 19.4% and 22.4% and ventilatory threshold by 19.5% and 18.5% and 18.5%, respectively (Burke, 1998).

Several previous studies (Morgan, Baldini, Martin, & Kohrt, 1989; Powers, Dodd, Deason, Byrd, & McKnight, 1983) have shown that maximal oxygen consumption (VO_2max), running speed at the lactate limit, and running economy at higher speeds are significantly related to success in running. Results in long-term aerobic activities have high correlations with the intensity of physical activity at the anaerobic threshold (Costill et al., 1985; Farrell et al., 1979; Rhodes & McKenzie, 1984) and are an indicator of individual aerobic capacity (Peronet et al., 1987; Tanaka, 1983). At a load of more than 60 to 90 seconds, energy needs are covered in a

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

situation where the work is increasingly aerobic, noting that at aerobic loads of constant intensity during the total duration of the load lactate may remain at normal level or slightly above normal (Malacko & Radjo, 2004). Lacour, Bouvat & Barthélémy (1990) investigated blood lactate concentrations as indicators of anaerobic energy consumption during 400m running. Ohkuwa, Kato, Katsumata, Nakao & Miyamura (1984) investigated blood lactates and glycerin after running at 400m and 3000m (in sprinters and long-distance runners), and concluded that peak blood lactate obtained after running at 400m could be used as an indicator of anaerobic performance in long-distance runners and untrained groups, but not in sprinters.

It is known that an increasing number of authors emphasize the importance of developing energy capacity in athletes regardless of the needs of the parent sport or the requirements of sports discipline (Bompa, 1999; Holmann & Hettinger, 2000). The Maximal Lactate Steady State (MLSS) or anaerobic threshold (second ventilation threshold) is defined by the intensity of work at which it is still possible to achieve a stable state of VO_2 and lactic acid in blood, ie. a

balance can be established between the process of accumulation and degradation of lactic acid (Barstow et al., 1993). The anaerobic threshold is reached at an intensity of about 80 - 90% VO_{2max} (in non-athletes at 65 - 70% VO_{2max} , and in trained people even at 95% VO_{2max} , depending on the training cycle - preparatory, pre-competition or competition), with a concentration of lactic acid in blood of about 3-5 mmol/l (Virus, 1995). Sports activities of relatively short duration and high intensity, for the realization of which there is essentially high level of anaerobic endurance and speed and strength endurance, draw most of their energy from anaerobic reserves, ie. from anaerobic energy capacities (Vucetic & Sentija, 2005).

As it can be seen, there is a lot of research that has studied the parameters of functional abilities in an attempt to find the most effective way to improve them, which would lead to improved results in running, and since there are many similar and different data on this topic, this paper was done with the aim of classifying the available papers of domestic and foreign authors, which would lead to conclusions applicable both in practice and for further research.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

METHODOLOGY

For the purposes of this research and finding appropriate original scientific papers in athletics and the importance of functional abilities to achieve results in running, and through keywords: training process in running, anaerobic trace, lactate concentration, maximum oxygen consumption, electronic databases were used - Medline, PubMed, Researchgate, Web of Science and Google Scholar. After removing irrelevant articles, the remaining articles were compiled and the full text of each was read to assess eligibility for inclusion. Eligibility criteria were created for the independent presentation of titles and abstracts found during the literature search and included topics related to short, middle and long distance running, functional abilities, improvement of VO₂max, lactate concentration. Based on the criteria and results of the research, the collected data are classified into four tables - according to research that examined functional abilities of short distance, middle distance and long distance runners, while the last table contains an overview of research that addressed the impact of training on functional abilities of runners.

RESULTS

Table 1. *Functional abilities researched in short-distance runners*

Author	Sample of respondents	Tests	Results
Kurelic et al. (1975)	34	– running at 100m, 1500m – heart rate and – vital capacity of lungs	– improved result at 1500m, – decrease in heart rate
Roberts et al. (1979)	sprinters and middle distance runners	– maximum aerobic power, – anaerobic threshold	– middle distance runners have a higher VO ₂ max and a higher anaerobic threshold
Nummela & Rusko (1995)	8 (short distance runners) 6 (middle distance runners)	– O ₂ consumption after exercise (EPOC)	– relative contribution of anaerobic energy yield ↓ from 80% to 60% during the first 15 seconds in both groups – No correlation was found between O ₂ deficiency and EPOC
Spencer, Gastin, & Payne (1996)	4 (short distance runners) 5 (middle distance runners)	– assessment of aerobic and anaerobic systems by AOD method	– There is no difference in AOD – In short distance runners ↑ VO ₂ max at 400 meters compared to middle distance runners during the 800m and 1500m races
Spencer & Gastin (2001)	20 (runners - 3 specialized for 200 m, 6 for 400 m, 5 for 800 m, 6 for 1500)	– relative contribution of aerobic and anaerobic energy system calculated by AOD method	– ↑ AOD with load duration during 200m, 400m and 800m running
Nagasawa (2013)	5 (middle distance runners) 5 (short distance runners) 6 (control group)	– rate of muscle reoxygenation (T1/2 StO ₂) – maximum oxygen consumption (VO ₂ max)	– T1/2 StO ₂ had a significant positive correlation with VO ₂ max

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

It is assumed that the correlation of functional abilities ($VO_2\max$, heart rate, lung capacity, oxygen deficit) is highly correlated with running at middle distances and depends to a large extent on their values. And as can be seen in Table 1, the authors dealt with the problem of changes in functional abilities during and after appropriate loads in short-distance runners, but also in middle-distance runners as a control group. Kurelic et al. (1975) were among the first performing researches on the connection between running middle distances and functional abilities, where on the sample of 34 respondents aged 22 years \pm 6 months he came to the conclusion that the results of running at 1500m are significantly related to heart rate as one type of functional abilities. By investigating the differences in the value of the anaerobic threshold and the maximum oxygen consumption ($VO_2\max$) in short-distance runners and middle-distance runners, Roberts et al. (1979), found that middle distance runners have a higher $VO_2\max$ and a higher anaerobic threshold. In a sample of 8 male short-distance runners and 6 male middle-distance runners, Nummela & Rusko (1995) analyzed the values of oxygen

deficiency (AOD), excessive oxygen consumption, and lactate concentration after exhaustive work (up to maximum). The results showed that the relative contribution of the anaerobic energy source decreased from 80% to 60% during the first 15 seconds of exhaustive work in both groups of respondents. Also, in both groups of respondents, the maximum oxygen consumption ($VO_2\max$) reached its peak in the interval from 25 to 40 seconds of exhaustive work in both groups. However, the relative contribution of the aerobic energy source was significantly higher in the group of middle distance runners (54-63%) compared to short distance runners (43-47%) and a statistically significant difference was observed ($p < 0.05$). Comparing $VO_2\max$ in different disciplines, Spencer, Gasin, & Payne (1996) tested 4 short distance runners and 5 middle distance runners. They came to the results that no significant differences in AOD were found between the respondents. They also came to the conclusion that short distance runners achieved in the 400m test (98% $VO_2\max$) while middle distance runners achieved in the 800m and 1500m running (90% and 94% $VO_2\max$). The relative contribution of the aerobic and

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

anaerobic energy system calculated by the accumulated oxygen deficiency (AOD) method was analyzed by Spencer & Gastin (2001) on a sample of 20 athletes grouped by running disciplines (200m N=3, 400m N=6, 800m N=5, 1500m N=6). The size of the oxygen deficit (AOD) increased with the duration of the load during the run at 200, 400 and 800 m (30.4 +/- 2.3, 41.3 +/- 1.0 and 48.1 +/- 4.5 ml/kg), but no further increase in running at 1500 m (47.1 +/- 3.8 ml/kg) was observed. The transition to consumption by a predominantly aerobic energy system occurred between 15 and 30 seconds when running at 400, 800 and 1500 m. In a sample of two groups, an experimental group consisting of 5 male long distance runners and 5 male short distance runners, and a control group consisting of 6 male subjects, Nagasawa (2013) analyzed oxygen saturation in muscle tissue (StO₂) in muscles vastus lateralis, the rate of muscle reoxygenation after exercise estimated at half the time required for StO₂ recovery

(T1/2 StO₂) and aerobic capacity estimated by measuring maximum oxygen consumption (VO₂max). The rate of reoxygenation (T1/2 StO₂) in middle distance runners (25.0 ± 4.5 seconds) was significantly longer than in the control group (1515.9 ± 1.6 seconds; p <0.01) and in short distance runners (18.0 ± 4.6 seconds; p <0.05). In all respondents (middle distance runners, short distance runners and control group), T1/2 StO₂ had a significant positive correlation with VO₂max (r = 0.75; p <0.01) and was longer in subjects with higher VO₂max. The primary limitations of most current literature investigating the impact of different training programs on sprint performance are that they usually involve only one training modality per research (i.e., do not investigate longitudinal effects of periodization) or per group of athletes, (Cormie et al. 2010) or are not based on elite sprinters (Bolger, Lyons, Harrison, & Kenny, 2015).

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Table 2. *Functional abilities researched in middle distance runners*

Author	Sample of respondents	Tests	Results
Krsmanovic (1987)	64	– functional abilities – 1500m	– statistically significant correlation of running at 1500 m with functional abilities
Vuksanovic (1999)	431	– motor skills – functional abilities	– positive influence of MS and FS on the results of running at 1000m
Stoiljkovic et al. (2004)	32	– Ventilation threshold (VT) measurement and $\dot{V}O_2\max$	– oxygen intake at ventilation threshold and $\dot{V}O_2\max$ increased significantly
Gasiin, Costill, Lawson, Krzeminski, & McConell (1995)	9 ($\dot{V}O_2\max = 57 \pm 3$) 12 ($\dot{V}O_2\max = 55 \pm 3$)	– supramaximal effort by the AOD method	– AOD is a reliable method of assessment of $\dot{V}O_2\max$
Mayhew (1977)	9	– $\dot{V}O_2\max$ – energy consumption	– oxygen consumption and running speed are correlated – calorie consumption is independent of running speed
Pate, Macera, Bailey, Bartoli, & Powell (1992)	188 (119 men, 69 women)	– heart rate and ventilation – $\dot{V}O_2\max$	– $\dot{V}O_2\max$, HR6 and VE6 are significantly positively correlated with $\dot{V}O_2-6$
Fletcher, Esau, & Macintosh (2009)	16	– $\dot{V}O_2\max$	– no difference in oxygen consumption in relation to speed was found – \uparrow caloric consumption with speed
Allen, Seals, Hurley, Ehsani, & Hagberg (1985)	16	– $\dot{V}O_2\max$ – lactate concentration	– older athletes had 9% \downarrow $\dot{V}O_2\max$ than younger ones – older athletes achieved 2.5 mmol blood lactate levels at a higher percentage of their $\dot{V}O_2\max$
Brisswalter & Legros (1994)	10	– running energy costs (C), ventilation (VE), respiratory frequency (RF), heart rate (HR), lactate concentration (La) and steps rate (SR)	– no significant differences were found between tests in C, VE, RF, HR, SR – significant everyday differences were found in La
Daniels & Oldrige (1971)	14 (Boys aged 10-15 years)	– submaximal and maximal $\dot{V}O_2$	– over a 12-month period \uparrow $\dot{V}O_2\max$
Daniels, Oldridge, Nagle, & White (1978)	20 (10-18 years of age)	– submaximal and maximal $\dot{V}O_2$	– $\dot{V}O_2\max$ is correlated with body weight – duration of training contributes to change of the submaximal $\dot{V}O_2$
Svedenhag & Sjödin (1984)	27 (middle and long distance runners) 2 (400m runners)	– $\dot{V}O_2\max$ – lactate concentration	– running speed corresponding to a blood lactate concentration of 4 mmol/l differed significantly between groups – blood lactate concentration after the test ($\dot{V}O_2\max$ test) was lower in long distance runners
Helgerud (1994)	6 men 6 women	– oxygen consumption during running (CR) – $\dot{V}O_2\max$	– $\dot{V}O_2$ ml \cdot kg ⁻¹ \cdot min ⁻¹ was significantly higher in men than in women
Saltin et al. (1995)	3 (Kenyan runners) 3 (Scandinavian runners)	– $\dot{V}O_2\max$	– the best Scandinavian runners did not differ significantly from the Kenyan runners in $\dot{V}O_2\max$, but none of the Scandinavians achieved such high individual values as were observed in some Kenyan runners
Duffield, Dawson, & Goodman (2005)	10 (3000m runners - 8 men, 2 women) 14 (1500m runners - 10 men, 4 women)	– oxygen intake, – blood lactate concentrations	– relative contribution of aerobic energy system for 3000 m was higher in women – concentration of lactate in the blood did not differ in relation to gender and event
McConnell & Clark	10	– $\dot{V}O_2\max$	– there were no significant differences in

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

(1988)			maximum oxygen uptake (VO ₂ max) between protocols
Lourenço, Barreto Martins, Tessutti, Brenzikofer, & Macedo (2011)	11	<ul style="list-style-type: none"> – VO₂max – Ventilation threshold (VT) and – respiratory compensation (RCP) 	– no significant differences were found in any of the analyzed parameters, including VT, RCP and VO ₂ max
Foster, Costill, Daniels, & Fink (1978)	26	<ul style="list-style-type: none"> – succinate dehydrogenase (SDH) – VO₂max 	– a small connection was established between SDH and VO ₂ max

To examine the correlation between functional abilities and running at 1500m, Krsmanovic (1987) tested 64 subjects aged 22 years +/- 6 months and concluded that there was a statistically significant correlation between the results of running at 1500 m and functional abilities (cardiovascular system). On a sample of 431 respondents aged 18 years +/- 6 months, Vuksanovic (1999) concluded that functional abilities have a significant impact on the results of running at 1000m. Stoiljkovic et al. (2004) measured the ventilation threshold (VT) and VO₂max in 32 subjects (22.3 +/- 2.5 years) and found that the oxygen intake at the ventilation threshold increased between the initial and final testing measures (34.8 ± 6 , 3 mlO₂/kg/min beginning, 41.3 ± 6.2 mlO₂/kg/min end) and VO₂max (52.1 ± 5.9 mlO₂/kg/min beginning, 57.1 ± 5.3 mlO₂/kg/min end). Assessment of the aerobic and anaerobic system by the method of accumulated oxygen deficiency AOD

(Medbo et al. 1988) was performed by Gassin et al. (1995) who tested 21 subjects with VO₂max ranging from 55 +/- 3 to 57 +/- 3 at supramaximal effort by the AOD method. After the analysis, they came to the conclusion that this method is quite reliable in assessing anaerobic capacity. To determine the correlation between oxygen consumption and running speed, Mayhew et al. (1977) tested 9 male subjects, middle distance runners. They obtained results with a high correlation between oxygen consumption and running speed (r = 0,917). Pate et al. (1992) in a sample of 188 subjects (119 men and 69 women) examined the correlation between VO₂max, heart rate (HR6) and ventilation capacity (VE6) with oxygen consumption at 6 mph running (VO₂-6). Correlation analysis revealed that VO₂max, HR6 and VE6 were significantly positively correlated with VO₂-6 (p <0,001). By conducting a running test for 5 minutes at speeds of 75%, 85% and 95% of the lactate

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

threshold, Fletcher et al. (2009) in a sample of 16 middle-distance runners examined the average oxygen consumption when running for 5 minutes at speeds corresponding to 75%, 85%, and 95% of the speed at the lactate threshold with a 5-minute break between phases. The results showed that the average oxygen consumption ranged from 221, 217 and 221 ml/kg and that there was no difference in oxygen consumption in relation to running speed ($p = 0.657$). VO_{2max} and lactate levels in younger and older athletes were addressed by Allen et al. (1985). They tested the maximum oxygen consumption and lactate level in 8 male middle distance runners aged 56 +/- 5 years and 8 male middle distance runners aged 25 +/- 3 years. The obtained results showed that older athletes had lower VO_{2max} by 9% ($p < 0.05$), but had lower blood lactate levels at a higher percentage of their VO_{2max} , which indicated that they could work closer to their VO_{2max} during the race. Brisswalter & Legros (1994) analyzed the energy costs of running (C), ventilation (VE), respiratory frequency (RF), heart rate (HR), lactate concentration (La) and steps rate (SR) in a sample of men and female middle distance runner at the usual pace of training on a

treadmill -75% VO_{2max} at speed (15.8 +/- .02 km.h⁻¹). They concluded that there was no significant difference between tests C, VE, RF, HR and SR between respondents in relation to gender, while only a difference was shown in test (La) $p < 0.025$. Daniels & Oldridge (1971) monitored the increase in submaximal and maximal VO_2 from exhaled air samples during a 22-month run during a treadmill test, on a sample of 14 boys aged 10-15 years. They proved that a certain period of growing up led to an increase in submaximal VO_2 from 2331 ml to 2839 ml, while there was no increase in maximum VO_2 . In a longitudinal study that lasted 6 years, Daniels et al. (1978), analyzed the correlation between submaximal and maximal VO_2 on a sample of 20 male subjects aged 10–18 years. Submaximal VO_2 was measured during the last 2 minutes of a 6-minute run at a speed of 202 m/min, and maximum VO_2 was measured during 5-8 minutes in the test performed to the maximum. VO_{2max} ranged from 1933 ml/min for 10-year-olds to 4082 for 18-year-olds. They concluded that in all longitudinal comparisons, maximum VO_2 changes with weight change, that is, that maximum VO_2 does not increase faster than the body weight

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

of active boys aged 10 to 18 years. On a sample of 29 middle and long distance runners who were divided into 6 groups (groups of runners from 400 m to marathon), Svedenhag & Sjödín (1984) analyzed $VO_2\text{max}$ and blood lactate concentration. Maximum oxygen consumption was analyzed based on running tests at speeds of 15 km/h and 20 km/h, and at these speeds it did not differ significantly between groups. Running speed corresponding to a blood lactate concentration of 4 mmol/l differed significantly between the groups with the highest value (5.61 m/s) in the 5000 to 10000 m group, while the blood lactate concentration after the tests was lower in long distance runners. Helgerud (1994) tested the maximum oxygen consumption $VO_2\text{max}$ and lactate threshold in 6 men and 6 women aged 20 to 30 years and concluded that men showed about 10% higher $VO_2\text{max}$, but no difference was found in relation to the level of lactate threshold between men and a women. By investigating the maximum oxygen consumption $VO_2\text{max}$ at different altitudes, on a sample of Kenyan and Scandinavian boys aged 14.2 +/- 0.2 years, Saltin et al. (1995) made a number of conclusions. At higher altitudes, inactive

Kenyan boys had a maximum oxygen intake ($VO_2\text{max}$) of 47 (44-51) ml/kg/min, while boys of similar age who regularly walked or ran but did not train for the competition reached $VO_2\text{max}$ above 62 (58 -71) ml/kg/min. Kenyan runners in active training had $VO_2\text{max}$ 68 +/- 1,4 ml/kg/min at higher altitudes, while they achieved $VO_2\text{max}$ 79,9 +/- 1,4 ml/kg/min at sea level. It was also observed that some Kenyan boys reached a $VO_2\text{max}$ of 85 ml/kg/min at sea level. The best Scandinavian runners did not differ significantly from the Kenyan runners in $VO_2\text{max}$ both at higher altitudes and at sea level, but none of the Scandinavian runners achieved such high individual values as observed in some Kenyan runners. It was concluded that it is physical activity during childhood, combined with intensive training in boys, that leads to higher $VO_2\text{max}$. Using the correlation between oxygen deficiency (AOD) and lactate concentration, which contribute to the values of the aerobic energy system in middle distance runners, Duffield et al. (2005), on a sample of 10 runners at 3000m (8 men and 2 women) and 14 runners at 1500m (10 men and 4 women) measured oxygen deficiency (AOD) and lactate concentration. The results of the analyzes

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

showed that the relative contribution of the measure-based aerobic energy system (AOD) for 3000 m was 86% (men) and 94% (women), while for 1500 m it was 77% (male) and 86% (female). Estimation of aerobic energy consumption based on lactate concentration did not differ between subjects in relation to gender and discipline ($p > 0.05$). McConnell & Clark (1988) studied a sample of 10 middle distance runners by analyzing the value of the maximum oxygen consumption VO_{2max} when performing the test where the speed increase protocol was changed 4 times, each by 2.5% every 2 minutes of performance. The results showed that there were no significant differences in the maximum oxygen consumption VO_{2max} between the protocols (P1, 65.0 +/- 5.6 ml/kg/min; P2, 64.5 +/- 5.3 ml/kg/min; P3, 66.2 +/- 3.9 ml/kg/min; P4, 64.7 +/- 5.8 ml/kg/min). By a test performed by repeating 4 protocols (where the running speed increased by 0.3 km/h every 25

seconds), Lourenço et al. (2011) analyzed maximal oxygen consumption VO_{2max} , ventilation threshold (VT), and respiratory compensation (RCP), in a sample of 11 male middle-distance runners. After the performed analyzes, no significant differences were found in any of the analyzed parameters during the implementation of the test protocol ($p > 0.05$). Foster et al. (1978) analyzed the maximum oxygen consumption VO_{2max} , muscle fiber composition and dehydrogenase (SDH) in a sample of 26 runners at medium distances using a treadmill test (running 1 mile, 2 miles and 6 miles). The results showed a low correlation between SDH and VO_{2max} ($r = -0.11$ for 1 mile, $r = -0.14$ for 2 miles and $r = -0.20$ for 6 miles), while the correlation of muscle fiber composition with VO_{2max} was at medium level ($r = -0.52$ for 1 mile, $r = -0.54$ for 2 miles and $r = -0.55$ for 6 miles).

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Table 3. *Functional abilities researched in long distance runners*

Author	Sample of respondents	Tests	Results
Bilat et al. (2003)	20 (elite Kenyan runners: 13 men and 7 women)	– VO ₂ max and speed at lactate threshold (vLT)	– the mean speed between vVO ₂ max and vLT did not differ significantly from the speed at 10 km, regardless of gender or type of training
Cavanagh & Williams (1982)	10 (recreational long- distance runners)	– O ₂ intake	– the mean increase in VO ₂ was 2.6 and 3.4 ml, respectively. kg ⁻¹ . min ⁻¹ at extreme short and long stride lengths
Coetzer et al. (1993)	9 white and 11 black South African middle and long distance runners	– race at 3000m and 5000m	– black runners had lower blood lactate concentration during exercise – time to fatigue was longer at black runners
Conley & Krahenbuhl (1980)	12 (long distance runners)	– oxygen intake (VO ₂) – VO ₂ max	– running economy makes up a large and significant amount of differences observed in the 10 km race
Davies & Thompson (1979)	13 (male ultramarathoners) and 9 (female marathoners)	– VO ₂ max	– VO ₂ max in men was higher than in women, but the consumption of O ₂ for a given speed was the same for both sexes
Craig & Morgan (1998)	9 (middle and long distance runners)	– VO ₂ max – running economy (RE) – oxygen deficit (AOD)	– no significant correlation was found between the 800 m running time and AOD
Boileau, Mayhew, Riner, & Lussier (1982)	74 elite runners (42 middle distance - MD, 32 long distance - LD)	– VO ₂ max	– mean VO ₂ max of LD runners was significantly higher than the value for the MD group – VO ₂ max is highly correlated with racing performance in the MD group
Daniels & Daniels (1992)	20 female and 45 male middle and long distance runners	– VO ₂ max – Heart rate (HR) – blood lactate level (HL _a)	– men have higher VO ₂ max than women and used less oxygen at normal absolute speeds, but VO ₂ did not differ between men and women
Taunton, Maron, & Wilkinson (1981)	15 male middle (MD) and long (LD) distance runners	– VO ₂ max – blood lactate level	– VO ₂ max values were higher in LD runners – blood lactate values were higher in the MD group compared to LD runners
Powers & Corry (1982)	5 (swimmers) 5 (cross-country runners)	– VO ₂ max	– VO ₂ max significantly higher in runners than in swimmers

Billat et al. (2003) analyzed VO₂max, speed at VO₂max (vVO₂max) and speed at the lactate threshold (vLT) in a sample of 20 elite Kenyan runners (13 men and 7 women) by 400 m track exhaustion test. They concluded that the mean velocity between vVO₂max and vLT did not differ significantly (P 0.87, 0.25, 0.87) regardless of gender or degree of training. Cavanagh &

Williams (1982) dealt with O₂ intake by the *Douglas Bag* method, in 10 recreational runners (mean VO₂max values of 64.7 ml/kg/min). The increase in O₂ was 2,6 and 3,4 ml/kg/min by changing the running technique. Comparing white and black runners at 3000 m and 5000 m, Coetzer et al. (1993) in a sample of 9 white and 11 black runners concluded that the superior

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

performance of black runners did not result from a higher percentage of type I fibers, but from black runners having lower blood lactate levels during load and longer time until onset of fatigue compared to white runners (169 +/- 65 seconds vs. 97 +/- 69 seconds; $p < 0.05$). In a sample of 12 middle distance runners, Conley & Krahenbuhl (1980) analyzed the correlation of $VO_2\max$ with running economy. The results showed that $VO_2\max$ has no statistically significant correlation with running economy ($r = -0.12$, $p = 0.35$), but noted that among highly trained and experienced runners of similar ability and similar $VO_2\max$ running economy makes a large and significant difference in achieved results of running longer distances. Comparing the maximum oxygen consumption $VO_2\max$ in a sample of 13 male marathoners and 9 female marathoners, Davis & Thompson (1979) concluded that a statistically significant difference ($p < 0.001$) was observed between the value of $VO_2\max$ in men of 72.5 ml/kg/min and in women of 58.2 ml/kg/min. The problem of predicting middle distance running results based on $VO_2\max$ values, running economy (RE), and oxygen deficiency (AOD) was addressed by Craing

& Morgan (1998). On a sample of 9 male medium and long distance runners (age 24.7 +/- 4.5 years, body weight = 69.4 +/- 8.5 kg, maximum oxygen consumption $VO_2\max$ 64.8 +/- 4.5 ml/kg/min), they analyzed the prediction of middle distance running results based on $VO_2\max$ values, running economy (RE) and oxygen deficiency (AOD). They concluded that no significant correlation was found between 800m running time and oxygen deficiency (AOD), and also that 800m running time could not be predicted based on the values of the other variables analyzed ($VO_2\max$ and running economy (RE)). By analyzing the maximum oxygen consumption at different running speeds, on a sample of 74 elite runners (42 middle distance runners (MD) and 32 long distance runners (LD), Boileau et al. (1982) came to certain conclusions. The mean value of maximum oxygen consumption $VO_2\max$ (ml/kg/min) in LD runners (76.9 ml/kg/min) was significantly higher than the value for MD runners (68.9 ml/kg/min) and a statistically significant difference ($p < 0.01$) was found. At different running speeds, the relative oxygen consumption (% VO_2) was lower for the LD group of runners by an average of 8% and a statistically significant

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

difference was found ($p < 0.01$). They also found that maximal oxygen consumption $VO_2\text{max}$ was more correlated with racing performance in the MD group of runners ($r = 0.70$) than in the LD group of runners ($r = 0.32$). Maximum oxygen consumption, heart rate and blood lactate levels, in a sample of 20 female and 45 male runners at medium and long distances, were also analyzed by Daniels, J. & Daniels, N. (1992) and they presented the obtained results. The results showed that men were taller, heavier, had a lower sum of six skin folds and higher maximum oxygen consumption $VO_2\text{max}$ than women ($p < 0.05$). Men used less oxygen (ml/kg/min) at normal absolute speeds, but no statistically significant difference was found between men and women. When comparing men and women with equal maximum oxygen consumption $VO_2\text{max}$, men were significantly more economical in energy consumption. It was concluded that men are more economical than women at absolute running speeds, but

when expressed in ml/km/kg there are no differences at similar running intensities. Also, when comparing men and women with equal maximum oxygen consumption $VO_2\text{max}$, men show better aerobic abilities. Maximum oxygen consumption $VO_2\text{max}$ and blood lactate levels in middle and long distance runners were also tested by Taunton et al. (1981). They measured the value of maximum oxygen consumption $VO_2\text{max}$ and the level of lactate in the blood in 15 male medium and long distance runners. The presented conclusions indicate that the values of maximum oxygen consumption $VO_2\text{max}$ were significantly higher in long-distance runners (68.7 ml/kg/min) compared to middle distance runners (62.8 ml/kg/min). Also, the values of lactate in the blood after maximum work were significantly higher in the group of runners at medium distances (15.0 mmol/l) compared to runners at long distances (11.9 mmol/l). Coory & Powers (1982) found that runners have higher $VO_2\text{max}$ than swimmers.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Table 4. *Impact of training on functional abilities*

Author	Sample	Tests	Results
Toncev (1988)	80 (students)	– Aerobic abilities	– Aerobic abilities improved
Burke et al. (1994)	80 (age 17 years +/- 6 months)	– lactate concentration and VO ₂ max	– results in both types of interval training showed an increase in VO ₂ max by 5% and 6%, lactate threshold by 19.4% and 22,4% and ventilatory threshold by 19.5% and 18.5%, respectively.
Stoiljkovic, Brankovic, Stoiljkovic & Joksimovic (2005)	90 (age 11 i 12 years)	– systolic and diastolic blood pressure – pulse frequency in load – absolute oxygen consumption – relative oxygen consumption	– increase in the level of functional abilities in the experimental period by applying the circular form of work is higher in the experimental group compared to the control group
Jakovljevic & Batricevic (2008)	38 (14 i 15 years +/- 6 months)	– heart rate while resting, – vital capacity of lungs, – systolic and diastolic blood pressure	– established a statistically significant difference in the transformation processes of the experimental model in the vital capacity of lungs and systolic and diastolic blood pressure
Franch, Madsen, Djurhuus, & Pedersen (1998)	36 (recreationists)	– VO ₂ max – RE (running economy)	– VO ₂ max and running speed at VO ₂ max are increased – Running economy is improved
Helgerud et al. (2007)	40	– VO ₂ max – heart strike volume (SV), – blood volume, – lactate threshold (LT) – running economy (RE)	– training process significantly influenced the increase of VO ₂ max in relation to the initial state – running economy (RE) increased statistically significantly by 10%

Dealing with the influence of a certain experimental program on functional abilities, Toncev (1988) tested 80 respondents aged 17 years +/- 6 months and came to the result that after the experimental exercise program, the functional abilities of the subjects were improved. Burke et al. (1994) dealt with a similar issue, they examined the effect of interval training on lactate level (lactate threshold) and VO₂max, in 80 respondents aged 17 years +/- 6 months. They concluded that VO₂max increased by 6% and the lactate threshold by

22.4%. Stoiljkovic et al. (2005) examined the influence of circular training on systolic and diastolic blood pressure, heart rate at workload, absolute and relative oxygen consumption, on a sample of 90 respondents aged 11 and 12 years. The obtained analysis results show that all parameters of functional abilities are increased after the circuit training treatment. The training model, which was aimed at developing functional abilities, was analyzed by Jakovljevic & Betricevic (2008) and they measured resting heart rate, vital capacity, systolic and

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

diastolic blood pressure in a sample of 38 respondents aged 14 and 15 years before the experimental training treatment. They came to the conclusion that the experimental treatment of training had a positive impact on the development of all abilities. By analyzing the impact of the training process in the frequency of exercise of 3 times a week conducted for 6 weeks, on a sample of 36 men engaged in recreational running, Franch et al. (1998) analyzed maximal oxygen consumption VO_2max and running economy (RE). Subjects were divided into three groups that conducted different trainings (exhaustive training with running longer distances (DT), long training (LIT) and training with running over shorter sections (SIT)). The results showed that VO_2max increased by 5.9 % ($p < 0.0001$), 6.0% ($p < 0.0001$) and 3.6% ($p < 0.01$) in DT, LIT and SIT, and running speed at VO_2max by 9% ($p < 0.0001$), 10% ($p < 0.0001$) and

4% ($p < 0.05$), respectively. Efficiency of the training process lasting 8 weeks on VO_2max , heart stroke volume (SV), lactate threshold (LT) and running economy (RE), on a sample of 40 men, divided into four groups - 70% of maximum heart rate; at the lactate threshold (85% HRmax); interval running 15/15 (15 s running at 90-95%; 4 x 4 min interval running (4 min running at 90-95% HRmax), were analyzed by Helgerud et al. (2007), and concluded that aerobic interval training of high intensity resulted in significantly increased VO_2max compared to long-distance training intensity and lactate threshold ($P < 0.01$). The percentage of increase for groups of 15/15 and 4 x 4 min was 5.5 and 7.2%, respectively, reflecting an increase in VO_2max from 60.5 to 64.4 ml x kg⁻¹ x min⁻¹ and 55.5 to 60.4 ml x kg⁻¹ x min⁻¹. SV increased significantly by approximately 10% after interval training ($P < 0.05$).

DISCUSSION

As can be seen in Table 1, to assess the functional abilities of short-distance runners, research was conducted on a relatively small sample - from 9 (Spencer, Gastin, & Payne, 1996) to 34 (Kurelic et al .,

1975), and mostly all are based on a comparison of the functional abilities of short distance runners with the functional abilities of middle distance runners, in which oxygen consumption and maximum oxygen

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

consumption were determined (Roberts et al., 1979; Nummela & Rusko, 1995; Nagasawa, 2013). as well as assessed the energy of aerobic and anaerobic systems (Spencer, Gastin & Payne, 1996; Spencer & Gastin, 2001) and muscle reoxygenation rate (Nagasawa, 2013). The results of the research indicate that middle distance runners have a higher maximum oxygen consumption and a higher aerobic threshold than short distance runners (Roberts et al., 1979), that the relative energy contribution during the first 15 seconds of running decreases in both, and that there is no difference in the value of oxygen deficiency (Nummela & Rusko, 1995; Spencer, Gastin, & Payne, 1996). Also, research has shown that the maximum oxygen consumption is higher in short distance runners compared to middle distance runners during the first 400m in the 800m and 1500m runs (Spencer, Gastin, & Payne (1996), that in short distance runners oxygen deficiency increases with duration of load (Spencer & Gastin, 2001), and that the rate of muscle relaxation and maximum oxygen consumption are positively correlated (Nagasawa, 2013). The sample of research respondents listed in Table 2 ranged from 6 to 431 runners on

middle distances of different ages and genders, and the research dealt with the assessment of submaximal and maximal oxygen consumption. Table 2 shows various studies of functional abilities, both $VO_2\text{max}$ and lactate levels during and after exercise, then energy consumption, up to heart rate. Methods for estimating $VO_2\text{max}$, both submaximal and maximal, and oxygen consumption during running were also examined. All this research was analyzed in connection with running middle and long distances. Evidence of a statistically significant correlation of functional abilities with running at middle distances was found in three studies (Krsmanovic, 1987; Vuksanovic, 1999; Duffield, Dawson & Goodman, 2005; Daniels, Oldridge, Nagle & White, 1978). The analysis of oxygen consumption, at different running speeds, was done by several researches, which came to different conclusions. Confirmed changes in $VO_2\text{max}$ at different running speeds, and their mutual correlation were determined in the research (Stoiljkovic et al. 2004; Mayhew, 1977; Pate, Macera, Bailey, Bartoli & powell, 1992; Daniels & Oldrige, 1971; Foster, Costill, Daniels & Fink, 1978), while research (Fletcher, Esau & Macintosh,

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

2009; Brisswalter & Legros, 1994; McConnell & Clark, 1988; Lourenço, Barreto Martins, Tessutti, Brenzikofer, & Macedo, 2011) did not confirm the correlation between $VO_2\text{max}$ and running speed. The correlation between $VO_2\text{max}$ and lactate levels was addressed by (Svedenhag & Sjödin, 1984,) who found differences in $VO_2\text{max}$ and lactate levels and proved that long distance runners have lower blood lactate concentrations than middle distance runners. Comparing different groups of respondents and their functional abilities (Helgerud, 1994; Saltin et al. 1995, Allen, Seals, Hurly, Ehsani & Hagberg, 1985) concluded that men have higher $VO_2\text{max}$ than women, and that there is no difference between European and African runners, and that older and more experienced runners have lower $VO_2\text{max}$ than younger runners, but also achieve lower blood lactate levels with a higher percentage of their own $VO_2\text{max}$. By estimating $VO_2\text{max}$ by different methods (Gasiin, Costill, Lawson, Krzeminski & McConell 1995), they concluded that the AOD method is very reliable in estimating $VO_2\text{max}$.

Table 3 shows papers that dealt with the values of $VO_2\text{max}$ depending on the length of the distance, also analyzed the values of $VO_2\text{max}$ in relation to the gender of respondents and economy of performing the running technique. A statistically significant difference between male and female long distance runners in $VO_2\text{max}$ consumption was demonstrated by (Davies & Thompson, 1979, Daniels & Daniels 1992), while (Daniels & Daniels 1992, Bilal & et al. 2003) proved that running speed at $VO_2\text{max}$ and the lactate threshold does not differ statistically in relation to the gender of runners and that VO_2 does not differ between the sexes at normal absolute running speeds. Analyzing the correlation of long distance running technique with functional abilities (Cavanagh & Williams, 1982; Conley & Krahenbuhl, 1980) proved the statistical association of running economy with $VO_2\text{max}$ values, while (Craig & Morgan, 1998) found that there was no statistical association between running results at 800m and oxygen deficit values. Comparing $VO_2\text{max}$ values and lactate levels between middle and long distance runners (Coetzer et al. 1993; Boileau, Mayhew, Riner & Lussier, 1982; Taunton,

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Maron & Wilkinson, 1981.), they proved that black runners have lower lactate concentrations and longer period of entering fatigue than white runners, then that long distance runners have higher $VO_2\text{max}$, and lower blood lactate levels than middle distance runners. Comparing $VO_2\text{max}$ values in different sports (Powers & Corry, 1982) proved that long distance runners have a statistically higher $VO_2\text{max}$ value than swimmers. Rotstein et al. (1986) found that nine-week interval training in athletes led to an increase in anaerobic threshold, $VO_2\text{max}$ and anaerobic capacity, as measured by the Wingate test. The role of aerobic and anaerobic capacities or the contribution of aerobic and anaerobic energy sources in running depends on the intensity and duration of running (Skof, Kropej & Milic, 2002). Several previous studies (Morgan, Baldini, Martin & Kohrt, 1989; Powers, Dodd, Deason, Byrd, & McKnight, 1983) have shown that maximal oxygen consumption ($VO_2\text{max}$), running speed at the lactate limit, and running economy at higher speeds are significantly associated with success in running.

Bernstein (1966) noted that in no area of human physiology is there such an

intensity of phylogenetic progress as in the area of motor functions. For these reasons, in order to establish the necessary and essential balance between vegetative and motor functions, various physical exercises are widely used, in terms of their dynamics and kinematics, which have a powerful and concentrated effect on different parts of the central, peripheral and vegetative nervous system, which contributes to their balance, and the application of appropriate diagnostic procedures and data analysis methods provides insight into the level of ability, characteristics and motor skills of the athlete, thus learning about possible barriers that are potential obstacles to further development and progress of the athlete (Mueller, 1999; Weineck, 2007 Reilly, 2007).

Table 4 shows the papers that analyzed the influence of a certain form of training process on functional abilities. By analyzing the effects of interval and circular form of training on functional abilities (Burke & et al. 1994, Stoiljkovic, Brankovic, Stoiljkovic & Joksimovic, 2005) proved a statistically significant difference between the initial and final measurement of certain

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

functional abilities (lactate concentration and $VO_2\text{max}$). By monitoring $VO_2\text{max}$ values, running economy, and vital lung capacity and systolic and diastolic blood pressure during the training process (Toncev, 1988; Jakovljevic & Baricevic, 2008; Franch, Madsen, Djurhuus & Pedersen, 1998; Helgerud et al., 2007), found a statistically significant increase in $VO_2\text{max}$ values between the initial and final measurements, an increase in vital capacity, a decrease in

systolic and diastolic blood pressure, and an increase in running economy. Testing 6 decathlon athletes, Popov (1980) found that certain parts of sprint training have a positive effect on functional abilities. Petrovic & Kukric (2006), on a sample of 12 respondents aged 20 years +/- 6 months, concluded that the training model had a positive impact on increasing functional abilities.

CONCLUSION

After analyzing all the above papers which have dealt with the functional abilities of short and medium distance runners, it can be seen that it is shown that middle distance runners have better functional abilities, ie higher maximum oxygen consumption, higher aerobic threshold and lower oxygen deficit than short distance runners. A review of all papers dealing with the functional abilities of middle distance runners, indicated that there is a large correlation between maximum oxygen consumption and lactate levels with running speeds and results achieved at middle distances, and it was also found that male middle distance runners have higher maximum oxygen consumption

and lower lactate levels than female runners. However, research on the functional abilities of long distance runners has shown that these runners have higher maximum consumption and lower lactate levels than middle distance runners, and that gender has a significant effect on the manifestation of maximum oxygen consumption, but that there are no differences between the sexes at running speeds at the level of maximum oxygen consumption and lactate levels. The analysis of papers that dealt with the influence of the training process on functional abilities showed that the implementation of various forms of training methods led to a statistically significant

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

increase in the value of maximum oxygen consumption, vital lung capacity, and running economy, but also to a decrease in systolic and diastolic blood pressure.

The limitation of this study was a limited access to the research studies, and a limited methodology applied in them, while many studies had too few respondents of different populations with a small number of elite runners, which caused low statistical power to draw general conclusions. Also, there is insufficient information on many years of experience, level of sports form, race categories, and descriptions of training and methods, which would enable the implementation of sufficient statistical analyzes, obtaining empirical information based on evidence and drawing valid conclusions. Useful methods were highlighted in the training papers, but short-

term data collection did not include a sufficient number of papers on the long-term impact of training. Accordingly, there is a need for a more systematic approach to research and the implementation of complex studies with a sufficient number of runners of all ages and both sexes of the elite level, to enable meaningful statistics, analysis and interpretation. Also, a cooperation of academic researchers, clubs and athletes in Europe is needed, which would enable the implementation of significant studies that provide a basis for evidence of improved performance and progress through the training system.

The results identified in this review provide a starting point for future research which identifies and quantifies predictors of functional performance as factors of success in short, middle, and long distance running.

REFERENCES

Allen, W., Seals, D., Hurley, B., Ehsani, A., & Hagberg, J. (1985). Lactate threshold and distance-running performance in young and older endurance athletes. *Journal of applied physiology*, 58(4), 1281-1284.

<https://doi.org/10.1152/jappl.1985.58.4.1281>

PMid:3988681

Barstow, T.J., R. Casaburi & K. Wasserman (1993). O₂ uptake kinetics and the O₂ deficit as related to exercise intensity and blood lactate. *Journal of Applied Physiology*, 75, 755-762

<https://doi.org/10.1152/jappl.1993.75.2.755>

PMid:8226479

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Berstajn, B. (1966). *Modeling school structures*. London, GBR.

Bilat, V., Lepetre, P., Heugas, A., Laurence, M., Salim, D., & Koralsztein, J. (2003). Training and bioenergetic characteristics in elite male and female Kenyan runners. *Medicine and science in sports and exercise*, 35(2), 297-304.

<https://doi.org/10.1249/01.MSS.0000053556.59992.A9>

PMid:12569219

Boileau, R., Mayhew, J., Riner, W., & Lussier, L. (1982). Physiological characteristics of elite middle and long distance runners. *Canadian journal of applied sport sciences*, 7(3), 167-172.

Bolger, R., Lyons, M., Harrison, A. J., & Kenny, I.C. (2015). Sprinting performance and resistance-based training interventions: a systematic review. *J Strength Cond Res*. 29(4).1146-1156.

<https://doi.org/10.1519/JSC.0000000000000720>

PMid:25268287

Bompa, T. (1999). *Periodization: Theory and methodology of training*. Champaign, IL: Human Kinetics.

Bompa, T. O. (2006). *Periodizacija - teorija i metodologija treninga*. Gopal, Zagreb.

Bowerman, J., Freeman, W. i Gambetta, V. (1999). *Atletika*. Gopal, Zagreb.

Brisswalter, J., & Legros, P. (1994). Daily stability in energy cost of running, respiratory parameters and stride rate among well-trained middle distance runners. *International journal of sports medicine*, 15(5), 238-241.

<https://doi.org/10.1055/s-2007-1021053>

PMid:7960317

Burke, J., Thayer, R., & Belcamino, M. (1994). Comparison of effects of two interval-training programmes on lactate and ventilatory thresholds. *Br J Sports Med*, (28), 18-21.

<https://doi.org/10.1136/bjism.28.1.18>

PMid:8044486 PMCID:PMC1332151

Carter, J. E. L., & Heath, B. H. (1990). *Somatotyping -Development and application*. Cambridge, United Kingdom: Cambridge University Press.

Cavanagh, P., & Williams, K. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine and science in sports and exercise*, 14(1), 30-35.

<https://doi.org/10.1249/00005768-198201000-00006>

PMid:7070254

Coetzer, P., Noakes, T., Sanders, B., Lambert, M., Bosch, A., Wiggins, T., & Dennis, S. (1993). Superior fatigue resistance of elite black South African distance runners. *Journal of applied physiology*, 75(4), 1822-1827.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

<https://doi.org/10.1152/jappl.1993.75.4.1822>

PMid:8282637

Conley, D., & Krahenbuhl, G. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and science in sports and exercise*, 12(5), 357-360.

<https://doi.org/10.1249/00005768-198025000-00010>

PMid:7453514

Cormie, P., M. R. McGuigan, et al. (2010). "Adaptations in athletic performance after ballistic power versus strength training." *Med Sci Sports Exerc* 42(8): 1582- 1598.

<https://doi.org/10.1249/MSS.0b013e3181d2013a>

PMid:20139780

Costill, D.L., et al. 1985. Metabolic characteristics of skeletal muscle during detraining from competitive swimming. *Medicine & Science in Sport & Exercise*, 17(3),339-343.

<https://doi.org/10.1249/00005768-198506000-00007>

Craig, I., & Morgan, D. (1998). Relationship between 800-m running performance and accumulated oxygen deficit in middle-distance runners. *Medicine and science in sports and exercise*, 30(11), 1631-1636.

<https://doi.org/10.1097/00005768-199811000-00012>

PMid:9813877

Čoh, M. (1992). *Atletika*. Ljubljana, Fakultet za sport.

Daniels, J., & Daniels, N. (1992). Running economy of elite male and elite female runners. *Medicine and science in sports and exercise*, 24(4), 483-489.

<https://doi.org/10.1249/00005768-199204000-00015>

PMid:1560747

Daniels, J., & Oldrige, N. (1971). Changes in oxygen consumption of young boys during growth and running training. *Medicine and science in sports*, 3(4), 161-165.

<https://doi.org/10.1249/00005768-197100340-00004>

PMid:5173386

Daniels, J., Oldridge, N., Nagle, F., & White, B. (1978). Differences and changes in VO₂ among young runners 10 to 18 years of age. *Medicine and science in sports*, 10(3), 200-203.

Davies, C., & Thompson, M. (1979). Aerobic performance of female marathon and male ultramarathon athletes. *European journal of applied physiology and occupational physiology*, 41(4), 233-245.

<https://doi.org/10.1007/BF00429740>

PMid:499187

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Duffield, R., Dawson, B., & Goodman, C. (2005). Energy system contribution to 1500- and 3000-metre track running. *Journal of sports sciences*, 23(10), 993-1002.

<https://doi.org/10.1080/02640410400021963>

PMid:16194976

Farrell, P.A., Wilmore J.H., Coyle, F.F., Billing, J.E., Costill, D.L. (1979). Plasma lactate accumulation and distance running performance. *Med. Sci. Sports* 11: 338-344.

<https://doi.org/10.1249/00005768-197901140-00005>

Fletcher, J., Esau, S., & Macintosh, B. (2009). Economy of running: Beyond the measurement of oxygen uptake. *Journal of applied physiology*, 107(6), 1918-1922. doi:10.1152/jappphysiol.00307.2009

<https://doi.org/10.1152/jappphysiol.00307.2009>

PMid:19833811

Foster, C., Costill, D., Daniels, J., & Fink, W. (1978). Skeletal muscle enzyme activity, fiber composition and VO₂ max in relation to distance running performance. *European journal of applied physiology and occupational physiology*, 39(2), 73-80.

<https://doi.org/10.1007/BF00421711>

PMid:689010

Franch, J., Madsen, K., Djurhuus, M., & Pedersen, P. (1998). Improved running economy following intensified training correlates with reduced ventilatory demands. *Medicine and science in sports and exercise*, 30(8), 1250-1256.

<https://doi.org/10.1097/00005768-199808000-00011>

PMid:9710865

Fratrić, F. (2012). *Osnove teorije i metodike sportskog treninga*. Retrived from http://www.senta-zentasport.rs/old/reci_nauke/teorija-sportskog-treninga-fratric/osnove-teorije-i-metodike-sportskog-treninga-skripta.pdf

Gasiin, P., Costill, D., Lawson, D., Krzeminski, K., & McConell, G. (1995). Accumulated oxygen deficit during supramaximal all-out and constant intensity exercise. *Medicine and science in sports and exercise*, 27(2), 255-263.

<https://doi.org/10.1249/00005768-199502000-00016>

Helgerud, J. (1994). Maximal oxygen uptake, anaerobic threshold and running economy in women and men with similar performances level in marathons. *European journal of applied physiology and occupational physiology*, 68(2), 155-161.

<https://doi.org/10.1007/BF00244029>

PMid:8194545

Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., . . . Hoff, J. (2007). Aerobic high-intensity intervals improve VO₂max more than moderate training. *Medicine and science in sports and exercise*, 39(4), 665-671.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

<https://doi.org/10.1249/mss.0b013e3180304570>

PMid:17414804

Hollmann, W., Hettinger, T. (2000). *Sportmedizin. Grundlege fur Arbeit, Training und Preventivmedizin*. Stuttgart, New York: Schattauer Verlag.

Idrizović, K. (2013). Razlike u dinamici razvoja motoričkih sposobnosti dječaka i djevojčica. In Findak, V. (Eds.). *Zbornik radova 22. Ljetna škola kineziologa Republike Hrvatske, Organizacijski oblici rada u područjima edukacije, sporta, sportske rekreacije i kineziterapije*, (pp. 444-449). Zagreb: Hrvatski kineziološki savez.

Jakovljević, D., & Batričević, D. (2008). Efekti modela eksplozivne snage na razvoj motoričkih i funkcionalnih sposobnosti učenika. *Sport Science*, 1(1). 30-33.

Krsmanović, R. (1987). Diskriminativna analiza funkcionalnih sposobnosti kardiovaskularnog sistema, motoričkih sposobnosti i rezultata trčanja na različitim dionicama. In Berković, L. (Ed.), *Zbornik radova III kongresa pedagoga fizičke kulture Jugoslavije*, 155-157. Novi Sad: RS.

Kurelić, N., Momirović, K., Stojanović, M., Šturm, J., Radojević, Đ., & Viskiće-Štalec, N. (1975). *Struktura i razvoj morfoloških i motoričkih dimenzija omladine [The structure and development of the morphological and motor dimensions of the young]*. Beograd, RS: Institut za naučna istraživanja Fakulteta za fizičko vaspitanje.

Lacour, J. R.; Bouvat, E.; Barthélémy J. C. (1990). Post-competition blood lactate concentrations as indicators of anaerobic energy expenditure during 400-m and 800-m races. *European Journal of Applied Physiology and Occupational Physiology*, (61), 172-176

<https://doi.org/10.1007/BF00357594>

PMid:2282899

Lourenço, T.F., Barreto Martins, L.E., Tessutti, L.S., Brenzikofer, R., & Macedo, D.V. (2011). Reproducibility of an incremental treadmill VO₂max test with gas exchange analysis for runners. *Journal of strength and conditioning research*, 25(7), 1994-1999.

<https://doi.org/10.1519/JSC.0b013e3181e501d6>

PMid:21487313

Malacko, J. i Rađo, I. (2004). *Tehnologija sporta i sportskog treninga*. Sarajevo.

Malousaris, G. G., Bergeles, N. K., Barzouka, K. G., Bayios, I. A., Nassis, G. P., & Koskolou, M. D. (2008). Somatotype, size and body composition of competitive female volleyball players. *Journal of Science and Medicine in Sport*, 11, 337-344.

<https://doi.org/10.1016/j.jsams.2006.11.008>

PMid:17697797

Mayhew, J. (1977). Oxygen cost and energy expenditure of running in trained runners. *British journal of sports medicine*, 11(3), 116-121.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

<https://doi.org/10.1136/bjism.11.3.116>
PMid:922272 PMCID:PMC1859586

McArdle, W. D., & Katch, V. I. (1991). *Exercise physiology: Energy, nutrition, and human performance*. 2nd ed. Philadelphia, PA: Lea & Febiger.
<https://doi.org/10.1249/00005768-199112000-00013>

McConnell, T., & Clark, B. (1988). Treadmill protocols for determination of maximum oxygen uptake in runners. *British journal of sports medicine*, 22(1), 3-5.
<https://doi.org/10.1136/bjism.22.1.3>
PMid:3370399 PMCID:PMC1478508

Morgan, D.W., Baldini, F.D., Martin, P.E. in Kohrt, W.M. (1989). Ten kilometer performance and predicted velocity at VO₂max among well-trained male runners. *Medicine and Science in Sports and Exercise*, 21(1), 78-83.
<https://doi.org/10.1249/00005768-198902000-00014>
PMid:2927305

Mueller, E. (1999). *Science and Elite Sport*. London: E&FN Spon.
<https://doi.org/10.4324/9780203984956>

Nagasawa, T. (2013). Slower recovery rate of muscle oxygenation after sprint exercise in long-distance runners compared with that in sprinters and healthy controls. *Journal of strength and conditioning research*, 27(12), 3360-3366.
<https://doi.org/10.1519/JSC.0b013e3182908fcc>
PMid:23604001

Nummela, A., & Rusko, H. (1995). Time course of anaerobic and aerobic energy expenditure during short-term exhaustive running in athletes. *International journal of sports medicine*, 16(8), 522-527.
<https://doi.org/10.1055/s-2007-973048>
PMid:8776206

Ohkuwa, T., Kato, Y., Katsumata, K., Nakao, T. & Miyamura, M. (1984). Blood lactate and glycerol after 400-m and 3,000-m runs in sprint and long distance runners. *European Journal of Applied Physiology and Occupational Physiology*, (53), 213-218
<https://doi.org/10.1007/BF00776592>
PMid:6542855

Pate, R., Macera, C., Bailey, S., Bartoli, W., & Powell, K. (1992). Physiological, anthropometric, and training correlates of running economy. *Medicine and science in sports and exercise*, 24(10), 1128-1133.
<https://doi.org/10.1249/00005768-199210000-00010>
PMid:1435160

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Peronnet, F., Thibault, G., Rhodes, E.C., McKenzie D.C. (1987). Correlation between ventilatory threshold and endurance capability in marathon runners. *Med. Sci. Sports Exerc.* 19: 610-615.
<https://doi.org/10.1249/00005768-198712000-00012>

Petrović, B., & Kukrić, A. (2006). Uticaj izabranog trenažnog modela na poboljšanje maksimalne brzine trčanja. *Glasnik Fakulteta fizičkog vaspitanja, Univerzitet u Banjoj Luci*, (2). 77-83.

Powers, N., & Corry, I. (1982). Maximal aerobic power measurement in runners and swimmers. *British journal of sports medicine*, 16(3), 154-160.
<https://doi.org/10.1136/bjism.16.3.154>
PMid:7139226 PMCID:PMC1858953

Powers, S.K., Dodd, S., Deason, R., Byrd, R. in McKnight, T. (1983). Ventilatory threshold, running economy and distance running performance of trained athletes. *Research Quarterly for Exercise and Sport*, 54(2), 179-182.
<https://doi.org/10.1080/02701367.1983.10605291>

Reilly, T. (2007) *The Science of Training - Soccer : A Scientific Approach to Developing Strength, Speed and Endurance*. Routledge.
<https://doi.org/10.4324/9780203966662>

Rhodes, E.C., D.C. McKenzie. (1984). Predicting marathon times from an aerobic threshold measurements. *Phys. Sportsmed.* 12: 95-99.
<https://doi.org/10.1080/00913847.1984.11701745>

Rotstein, A., Dofan, R., Bar-Or, O., and Tenenbaum, G. (1986). Effect of training on anaerobic threshold, maximal aerobic power and anaerobic performance of preadolescent boys. *Int. J. Sports Med.*, 7 286.
<https://doi.org/10.1055/s-2008-1025775>
PMid:3793338

Saltin, B., Larsen, H., Terrados, N., Bangsbo, J., Bak, T., Kim, C., . . . Rolf, C. (1995). Aerobic exercise capacity at sea level and at altitude in Kenyan boys, junior and senior runners compared with Scandinavian runners. *Scandinavian journal of medicine & science in sports*, 5(4), 209-221.
<https://doi.org/10.1111/j.1600-0838.1995.tb00037.x>
PMid:7552766

Spencer, M., & Gastin, P. (2001). Energy system contribution during 200- to 1500-m running in highly trained athletes. *Medicine and science in sports and exercise*, 33(1), 157-162.
<https://doi.org/10.1097/00005768-200101000-00024>
PMid:11194103

Spencer, M., Gastin, P., & Payne, W. (1996). Energy system contribution. *New studies in athletic*, 11(4), 59-65.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

Svedenhag, J., & Sjödín, B. (1984). Maximal and Submaximal Oxygen Uptakes and Blood Lactate Levels in Elite Male Middle- and Long-Distance Runners. *International journal of sports medicine*, 5(5), 255-261
<https://doi.org/10.1055/s-2008-1025916>

PMid:6500792

Stoiljković, S., Ilić, N., Stefanović, Đ., Mitić, D., Mitrović, D., Popović, D., Nešić, D. & Mazić, D. (2004). Oxygen uptake at ventilatory threshold and VO₂max, before and after eight weeks of endurance training. *Godišnjak Fakulteta sporta i fizičkog vaspitanja*, (12). 83-98.

Stoiljković, S., Branković, N., Stoiljković, D., & Joksimović, A. (2005). Valorizacija "kružnog" oblika rada za razvoj dinamičke snage u nastavi fizičkog vaspitanja. *Sport Mont*, 6-7(III). 273-282.

Škof, B., Kropelj, V.L., in Milić, R. (2002). Povezanost dimenzij sestave telesa in aerobne učinkovitosti pri otrocih med 10 in 14 let [The correlation between body composition dimensions and aerobic ability of children aged 10 to 14 years]. In R. Pišot, V. Štemberger, F. Krpač, & T. Filipčič (Eds.), *Otrok v gibanju: zbornik prispevkov: proceedings* (pp. 372-378). Ljubljana: Pedagoška fakulteta.

Tanaka, K. (1983). Relationship of anaerobic threshold and onset of blood lactate accumulation with endurance performance. *European Journal of Applied Physiology*, 52: 51-56.

<https://doi.org/10.1007/BF00429025>

PMid:6686129

Taunton, J., Maron, H., & Wilkinson, J. (1981). Anaerobic performance in middle and long distance runners. *Canadian journal of applied sport sciences*, 6(3), 109-113.

Tončev, I. (1988). Uticaj programiranog modela trčanja na ventilacijske funkcije, motoričke sposobnosti, kognitivne i konativne osobine omladinaca. In Berković, L. (Ed.), *Zbornik radova nastavnika i saradnika fakulteta Fizičke kulture u Novom Sadu*, (133-144). Novi Sad: RS.

Viru, A. (1995). *Adaptation in sport training*. Boca Raton, FL: CRC Press Inc.

Vučetić, V., Šentija, D. (2005). Doziranje i distribucija intenziteta u trenažnom procesu - zone trenažnog intenziteta. *Kondicijski trening. UKTH, Zagreb* 2(3) 2005. (36-42).

Vuksanović, M. (1999.) *Utvrđivanje efikasnosti nastave fizičkog vaspitanja u odnosu na postignute rezultate u atletici*. Doktorska disertacija. Fakultet sporta i fizičkog vaspitanja, Univerzitet Novi Sad.

Weineck, J. (2007). *Optimales Training*. Berlin, GER: Spitta Verlag.

PARAMETERS OF FUNCTIONAL ABILITIES IN RUNNING – RESEARCH REVIEW

SAŽETAK

Trčanje kao atletska disciplina iziskuje velik nivo izdržljivosti i brzinske izdržljivosti, što je u direktnoj vezi sa kardiovaskularnim i respiratornim sistemima, odnosno sa sposobnošću organizma sportiste da podnese opterećenja koja, pa se kao relevantni faktori za uspjeh trčanju navode: anaerobna snaga i maksimalna potrošnja O_2 , koncentracija mliječne kiseline i manjak kisika, sposobnost podnošenja stresa, visoko sposobnost koncentracije i njeno zadržavanje tokom dužeg vremena. Mnogo je istraživanja koja su se bavila izučavanjem parametara funkcionalnih sposobnosti u pokušaju nalaženja najefikasnijeg načina poboljšanja istih, a budući da je mnogo sličnih i različitih podataka o toj tematici ovaj rad je urađen sa ciljem klasifikovanja dostupnih radova domaćih i stranih autora čime bi se izveli zaključci primjenljivi kako u praksi tako i za dalja istraživanja.

Za potrebe ovog istraživanja analizirani su originalni naučni radovi koji su se bavili funkcionalnim sposobnostima kao faktorima uspjeha u trčanju na kratke, srednje i duge distance te uticajem treninga na funkcionalne sposobnosti, pronađeni na elektronskim bazama podataka - Medline, PubMed, Researchgate, Web of Science and Google Scholar. Istraživanja korištena u ovom pregledu pratila su transverzalno vrijednosti submaksimalne i maksimalne potrošnje kiseonika, energetske sisteme, vrijednosti frekvencije srca, plućnu ventilaciju, koncentraciju laktata u krvi, kao i njihove promjene nakon longitudinalne provedbe eksperimentalnih protokola i trenažnih procesa. Budući da su prikupljena istraživanja imala premalo ispitanika različite populacije sa malom brojnošću elitnih trkača, te da nisu imala dovoljno informacija o dugogodišnjem iskustvu, nivou sportske forme, kategorijama trka, te opisa treninga i metoda, dobijanje empirijskih informacija utemeljenih na dokazima bilo je ograničeno, kao i izvedba valjanih zaključaka. Shodno navedenom, postoji potreba za više sistematskim pristupom istraživanjima i provedbi kompleksnih studija sa dovoljnim brojem trkača svih uzrasta, oba pola elitnog nivoa, te saradnja akademskih istraživača, klubova i sportista što bi omogućilo provođenje studija koje bi omogućile značajne statističke podatke, analize i interpretacije. Rezultati identifikovani u ovome pregledu pružaju polazište za buduća istraživanja koja identifikuju i kvantifikuju prediktore funkcionalnih performansi kao faktore uspjeha trčanja na kratkim, srednjim i dugim distancama.

Ključne riječi: maksimalna potrošnja kiseonika, koncentracija laktata, kratke distance, srednje distance, duge distance, trenažni proces

Received :26.05.2020.

Approved: 23.11.2020.

Correspondance:

Radosav Đukić, PhD.

Spartamedic, Vienna, Austria

Tel.: +43 664 1330916 E-mail: rade.djukic@chello.at