HUMAN MOVEMENT
2013, vol. 14 (4), 360–365

LACTATE AND GLUCOSE CONCENTRATIONS IN ASSESSING ANAEROBIC CAPACITY IN AN ELITE JUNIOR SWIMMER – A CASE STUDY

doi: 10.2478/humo-2013-0044

PIOTR MAKAR, GRZEGORZ BIELEC *
University School of Physical Education and Sport, Gdańsk, Poland

ABSTRACT
Purpose. The aim of the study was to assess lactate and glucose concentrations as indicators of anaerobic capacity in a highly-ranked female junior swimmer. **Methods.** Ten trials of a 5 × 200 m backstroke step test were performed between December 2008 and July 2011. Each trial was video-recorded and blood samples were drawn from the ear lobe 1 min after completion of each step to measure lactate and glucose concentrations. **Results.** During maximal effort, lactate concentrations of 5.1 to 13.1 mmol · l^{-1} were recorded, while glucose concentration varied from 6.6 to 8.1 mmol · l^{-1}. Correlations between lactate and glucose concentrations were significant in most tests. The shape of lactate and glucose curves revealed an improvement in the swimmer's endurance ability during subsequent tests. **Conclusions.** Analysis of fluctuations in lactate and glucose concentrations appears to be a relevant indicator of the anaerobic capacity of experienced swimmers.

Key words: swimming, training, intensity, test

Introduction

The lactate threshold refers to the intensity of exercise at which there is an abrupt increase in blood lactate levels. Bompa [1] describes the lactate threshold as the moment at which anaerobic metabolism starts to play a crucial role in providing energy and when aerobic processes are unable to remove built-up lactic acid and cannot counteract the increasing acidity of the muscles. According to Heck et al. [2], the highest blood lactate concentration (BLC) that increases by no more than 1 mmol · l^{-1} during the final 20 minutes of exercise at a constant workload can be termed as the maximal lactate steady state (MLSS). In the case of most exercise tests, this is cited as the mean BLC of samples drawn at the 15th, 20th, 25th and 30th minutes of such tests. Other researchers claim that measurement of MLSS should entail participants to repeat a 30-min constant workload test multiple times [3, 4].

The practical use of using lactate tests in swimming training has been described by many authors [5, 6]. For example, Pelayo et al. [7] conducted a study on swimmers specializing in the 200 m freestyle over a 23 week-long training period. Weeks 2–10 were devoted to aerobic exercise while Weeks 10–21 consisted of only anaerobic exercise. Depending on the type of exercise performed, different lactic acid production was observed at the 3rd and 12th minutes after a maximal test was administered. The study indicated that the percentage value of lactate concentration could provide an efficient marker when monitoring the impact of aerobic and anaerobic training.

Besides lactate levels, analysis of the changes in swimmers' glucose levels can also be useful in the evaluation and control of their physical performance. The primary justification for this stems from the fact that most swimming competitions are held at the 100 and 200 m distances, where the time of maximal physical effort among the world's best swimmers varies from 47 s to over 2 min and 20 s. Such efforts trigger the resynthesis of adenosine triphosphate (ATP) in the glycolytic pathways, the product of which – lactic acid – has been mentioned previously as a widely used diagnostic parameter in sport training. Therefore, analysis of glucose levels, the substrate of the glycolytic pathway, can serve as a useful indicator of an athlete's fitness level. However, previous studies analysing the effects of physical effort in an aquatic environment on glucose levels have been largely conducted on diabetic populations [8–11]. Also of relevance was one study that concentrated on investigating the influence of carbohydrate supplementation on swimming results [12]. In addition, the results of a recent study conducted on competitive swimmers by Sengoku et al. [13] found that a few weeks' worth of training were enough to induce slight changes in blood glucose concentration.

In order to further analyse the role of lactic acid and blood glucose levels in assessing the anaerobic capacity of elite swimmers, the aim of this study was to verify whether increasing the intensity of effort during an exercise test could demonstrate a relationship between blood glucose and lactate concentrations. Additionally, it was hoped to determine whether glucose and lactate concentrations are essentially correlated.

* Corresponding author.

Material and methods

The study was conducted on a healthy female member of the Polish National Junior Swimming Team, who at the initial phase of the study was aged 16 years, 176 cm tall and weighed 69 kg. She was a world-class junior category competitor and a medal winner in the backstroke at junior World and European championship events.

The study procedure outlined below was approved by the Ethics Committee of the University School of Physical Education and Sport in Gdańsk, Poland and the athlete provided her written informed consent prior to participation in the study.

Measurement of the swimmer's anaerobic capacity was conducted using a 5 × 200 m step test, which consisted of five 200 m backstroke swims performed with increasing intensity every subsequent step (200 m). The first step was completed at 75–80% of the swimmer's maximal velocity for the 200 m distance, the second at 81–85%, the third at 86–90%, the fourth at 91–95% and the last swim performed at maximal velocity. Rest was provided between each step and lasted 3, 5, 7 and 20 min, respectively. Before each step test the swimmer performed a standard warm-up in the water (600 m of standard preparation exercises, 400 m of backstroke technique exercises, 4 × 25 m backstroke at increasing velocity every 45 sec, then 400 m of free swimming). All trials were filmed, measured, and analysed using a DCR-HC19E video camera (Sony, Japan) filming at 25 Hz and Adobe Premiere Pro ver. 7.0 (Adobe Systems, USA) video software.

Capillary blood samples were drawn from the ear lobe 1 min after each step was completed. For some tests, samples were also drawn at the 3rd and 4th min in order to verify maximal lactate and glucose concentrations. Lactic acid concentration was assessed using a Lactate Scout analyser (SensLab, Germany), whereas glucose level was measured with a FreeStyle Lite glucometer (Abbott Diabetes Care, USA). Each blood sample was examined twice by the lactate analyser and glucometer. A coefficient of variation (CV) was calculated from each pair of measurement results. The range of CV varied from 2.5 to 3.5.

Altogether four step tests in the 2008/2009 season (December-June) and six tests in the 2010/2011 season (September-July) were used for analysis. Results from the 2009/2010 season were omitted from analysis as only two tests were properly conducted during this period. Therefore, comparison of the results were made only between the 2008/2009 and 2010/2011 training seasons.

All trials were conducted in the same 25 m indoor swimming pool. The examined athlete followed a balanced diet recommended for swimmers [14, 15] and performed each trial on an empty stomach. Throughout the study, the athlete's body composition was assessed weekly by a Bio Scan 920-2 device (Maltron, UK). Blood glucose concentration was also assessed every week before a morning training session. The participant's training units were planned and conducted according to Maglischo's guidelines for middle-distance swimmers [16].

Statistical analysis was conducted with Statistica ver. 10 (StatSoft, USA). Arithmetic means and Spearman's rank correlation coefficient were used for statistical evaluation of the study results. The level of statistical significance was set at $p < 0.05$.

Results

Lactic acid concentrations (LA) obtained during the first step test in December 2008 were found to almost perfectly match the lactate curve (Fig. 1). Three months later, during the second test in March 2009, the swimmer had an uncharacteristically higher lactate concentration during Step 2 (4.2 mmol · l^{-1}), i.e. at a lower swimming velocity, than during the higher velocity performed in Step 3 (3.7 mmol · l^{-1}). The level of anaerobic power, expressed as maximal acidification, at the same pace (step) as in December 2008 decreased by 1.4 mmol · l^{-1}. When comparing the results of the test conducted in April 2009 with the previous one, it was observed that blood lactate concentration was 0.9 mmol · l^{-1} at a swimming velocity of 1.21 m · s^{-1}, while only slightly larger (1.4 mmol · l^{-1}) at 1.27 m · s^{-1}. Additionally, swimming velocity close to the onset of blood lactate accumulation (OBLA) was increased at a lower acidity level. Furthermore, the results of the last step improved from 2 min 19 s to 2 min 17 s with only a minor increase in maximal lactate concentration. When compared to the third lactate test (April 2009), the results of the June 2009 test showed additional improvement in swimming velocity close to the OBLA (April 2009: 1.36 m · s^{-1} at 4.4 mmol · l^{-1} acidity vs. June 2009: 1.38 m · s^{-1} at 4.3 mmol · l^{-1}). Maximal swimming velocity remained constant although with a decrease in acidity (from 12.3 mmol · l^{-1} to 11.8 mmol · l^{-1}, respectively).

Glucose concentrations measured during the step tests held over the 2008/2009 training season are presented in Figure 2. The shape of the glucose curve for the March 2009 test is slightly different from the one recorded in December 2008. There is a decrease between the first and the second step but only by 0.1 mmol · l^{-1}. Additionally, there is an almost linear relationship between swimming velocity and glucose concentration from the second step of the test to the last step. The shapes of the glucose curves recorded for December 2008 and March 2009 are completely different in the first three steps of the tests, while there is a very similar inclination and direction of the data between the results of the fourth and fifth steps. On the basis of the glucose curve shapes, it can be observed that in March 2009 the swimmer covered the steps at 75–80% and 81–85% intensity with lower glucose concentrations than in the preceding test. However, a different situation can be seen in the

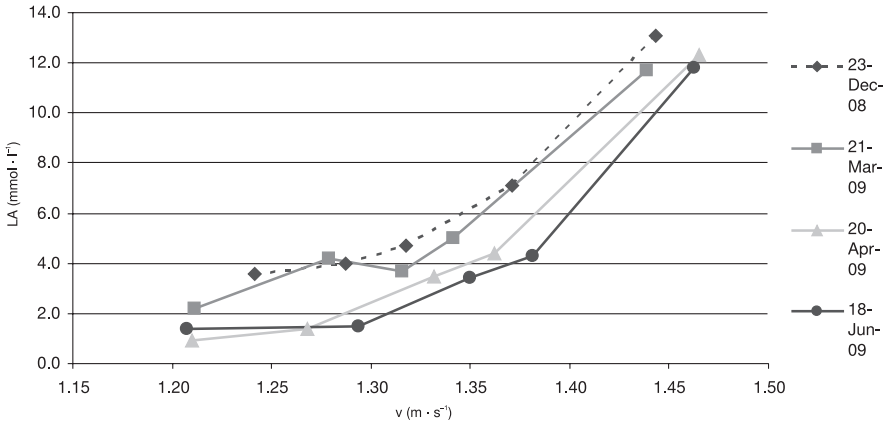

Figure 1. Lactate velocity curves during the 5 × 200 m backstroke step tests in the 2008/2009 season; LA – blood lactate concentration, v – swimming speed

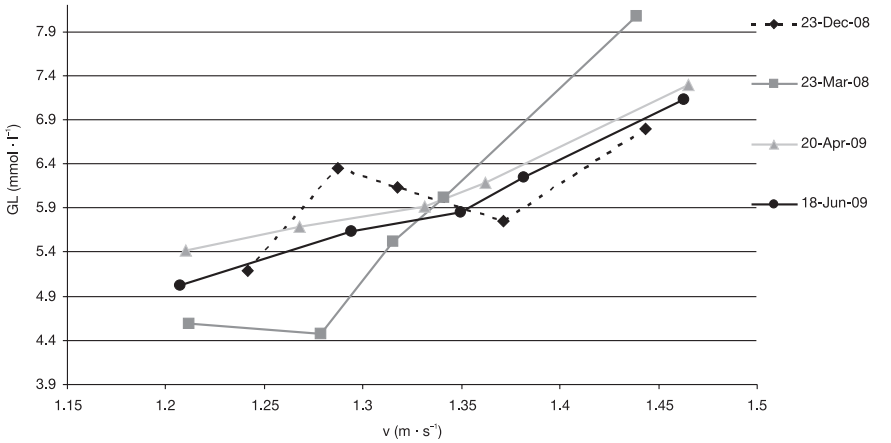

Figure 2. Glucose concentrations for swimming velocities during the 5 × 200 m backstroke step test in the 2008/2009 season; GL – glucose concentration, v – swimming speed

Table 1. Correlation of lactate and glucose concentrations (mmol · l^{-1}) during the 5 × 200 m backstroke step test in the 2008/2009 season

Intensity	23 Dec. 2008		21 Mar. 2009		20 Apr. 2009		18 June 2009	
	LA	GL	LA	GL	LA	GL	LA	GL
75–80%	3.6	5.2	2.2	4.6	0.9	5.4	1.4	5.0
81–85%	4.0	6.4	4.2	4.5	1.4	5.7	1.5	5.6
86–90%	4.7	6.1	3.7	5.5	3.5	5.9	3.4	5.9
91–95%	7.1	5.7	5.0	6.0	4.4	6.2	4.3	6.2
Max	13.1	6.8	11.7	8.1	12.3	7.3	11.8	7.1
Spearman's ρ	0.600		0.700		1.000*		1.000*	

(* $p < 0.05$)

case of the steps performed at maximal intensity, with the shapes of the glucose curves recorded in April 2009 and June 2009 being very similar. In June 2009, the differences of the results were the smallest in comparison with the previous test. However, the recorded values were smaller than those in the previous test.

Analysis was then performed to check whether lactate and glucose correlations were similar among all the performed tests. It was found that there were some differences in correlation results among the tests (Tab. 1).

On the basis of the plotted glucose and lactate curves recorded in the 2010/2011 season, the improvement in anaerobic capacity was not as systematic and evident as in the 2008/2009 season. The results of the step test performed in September 2010 show more advantageous fluctuations in lactate concentrations than then successive test performed in November 2010 (Fig. 3). At a swimming velocity of 1.33 m · s^{-1}, close to the OBLA, blood lactate concentration was 4.2 mmol · l^{-1}, while at 1.32 m · s^{-1} lactate was higher, at 5.1 mmol · l^{-1}. A similar situation was observed in the tests conducted in April and June 2011. The swimmer had better aerobic capacity in April 2011 (3.7 mmol · l^{-1} lactate concentration at 1.35 m · s^{-1}), but her abilities to perform at submaximal and maximal intensity anaerobic efforts noticeably decreased (5.1 mmol · l^{-1} lactate concentration).

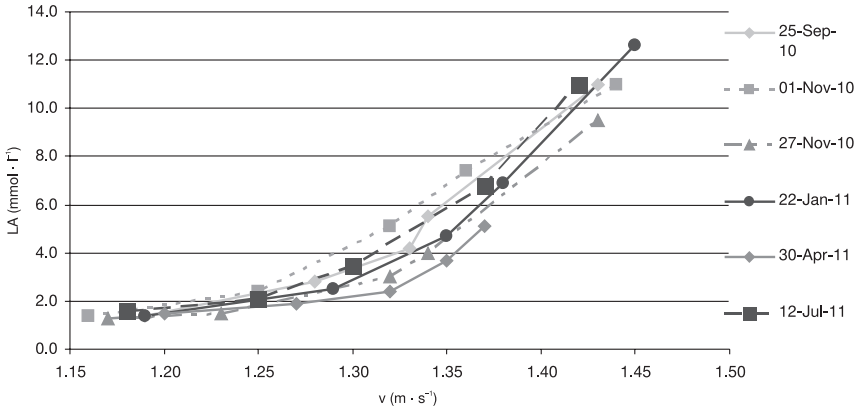

Figure 3. Lactate velocity curves during the 5 × 200 m backstroke step tests in the 2010/2011 season; LA – blood lactate concentration, v – swimming speed

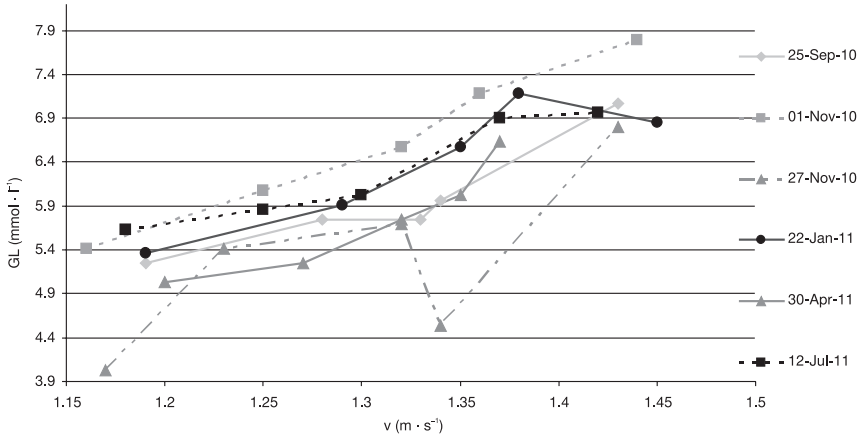

Figure 4. Glucose concentrations for swimming velocities during the 5 × 200 m backstroke test in the 2010/2011 season; GL – glucose concentration, v – swimming speed

Table 2. Correlation of lactate and glucose concentrations (mmol · l^{-1}) during the 5 × 200 m backstroke step tests in the 2010/2011 season

Intensity	25 Sept. 2010		01 Nov. 2010		27 Nov. 2010		22 Jan. 2011		30 Apr. 2011		12 July 2011	
	LA	GL	LA	GL	LA	GL	LA	GL	LA	GL	LA	GL
75–80%	1.4	5.2	1.4	5.4	1.3	4.0	1.4	5.4	1.5	5.0	1.6	5.6
81–85%	2.8	5.7	2.4	6.1	1.5	5.4	2.5	5.9	1.9	5.2	2.1	5.9
86–90%	4.2	5.7	5.1	6.6	3.0	5.7	4.7	6.6	2.4	5.7	3.5	6.0
91–95%	5.5	6.0	7.4	7.2	4.0	4.5	6.9	7.2	3.7	6.0	6.8	6.9
Max	11.0	7.1	11.0	7.8	9.5	6.8	12.6	6.9	5.1	6.6	11.0	7.0
Spearman's ρ	0.974*		1.000*		0.700		0.900*		1.000*		1.000*	

(* $p < 0.05$)

The shapes of the glucose curves in the 2010/2011 season present noticeable differences for the athlete's anaerobic capacity when compared with 2008/2009 season. The highest glucose concentration (approx. 7.8 mmol · l^{-1}) at the highest velocity was achieved in November 2010 (Fig. 4). During the other step tests, glucose concentration varied from 6.8 to 7.1 mmol · l^{-1}, reaching its lowest level of 6.6 mmol · l^{-1} in April 2011. The most varied results in that season were obtained in November 2010 and April 2011. Comparison of these two results show that a lower glucose concentration in April and where the swimmer's velocity did not exceed 1.37 m · s^{-1} (Fig. 4). Correlations between lactate and glucose concentrations in the 2010/2011 season were strong and significant for most of the tests (Tab. 2).

Discussion

In competitive sport, it is extremely crucial to monitor the adaptive changes that an athlete undergoes throughout the training cycle. Knowing an athlete's level of physiological preparation allows trainers to select appropriate training methods and avoid overtraining caused by excessive training loads. In swimming, controlling the effectiveness of the training process by monitoring changes in lactate concentration is considered an efficient assessment tool, especially if such lactate tests are frequently administered. However, due to the severe physical and mental strain a swimmer undergoes during a lactate test, it is recommended to limit their application to no more than several times per season [17, 18].

The correlation between lactic acid production and exercise intensity is widely known and has been commonly applied in training practice. Even though the production of lactic acid from glucose is also recognized, there is little scientific evidence showing that it can be directly connected with the body's reaction to blood glucose concentration during exercise of varied intensity. As is commonly known, this is a shared process that occurs via carbohydrate metabolism during physical exercise. During exercise of low and medium intensity, glucose concentration usually remains steady, with a tendency to decrease during prolonged efforts. However, exercise of increasing intensity lasting longer than approximately 90 minutes may cause a significant decrease in glucose concentration [19]. This process is regulated by means of insulin concentration, which inhibits glycogenolysis and gluconeogenesis.

In the present study, the evidently low correlation between LA and GL concentrations in the test conducted in December 2008 could have been caused by a too high velocity in the first step of the 5 × 200 m test. The results of the test performed in April 2009 were noticeably different in this respect. It can be seen that the swimmer began the test at the same velocity as the previous month; however, her better aerobic capacity (LA lower by 1.3 mmol · l^{-1}) at this point in time may have negated the need for an increased amount of hepatic glucose. In the literature, it was acknowledged that trained individuals produce more hepatic glucose during prolonged and more intensive exercise [20]. The lactate curve recorded in April 2011 was found to have shifted further rightward, indicating that the athlete's condition had even further improved. Nevertheless, this test also showed the lowest value recorded for LA concentration during maximal effort, which may have been caused by insufficiently filled carbohydrate depots or, as it is also known, the "lactate paradox" [21].

During the second and fourth steps (81–95% intensity range) of the tests conducted in the 2010/2011 season, it was expected that the swimming velocity would increase; instead, it was found to have decreased. A weaker relationship between the analysed variables was also noted in November 2010, which, from a coaching perspective, is quite surprising. In terms of training load, this period was essentially similar to the other tests. Therefore, either chronic fatigue or an insufficient amount of carbohydrates in the athlete's diet may be an explanation for this finding, as Paschoal and Amancio recorded muscle degradation as the result of an improper carbohydrate diet among competitive swimmers [22].

The present study indicates that the relationship between glucose and lactic acid concentrations in successive lactate tests may be diametrically opposed, suggesting that such a relationship may be the result of factors such as diet and previously applied training loads. As claimed by Maglischo [16], the main role of training is to increase the capacity of the energy sources involved during swimming. Although in some sport disciplines the ratio of energy provided by the aerobic/anaerobic pathways may not be as important, this factor plays a crucial role in the process of swimming training where considerable focus is placed on the development of endurance, strength and speed. In this regard, Kabaskalis et al. highlighted the practical usefulness of monitoring dietary intake and the biochemical status of competitive swimmers [23]. The continuation of studies and further analysis of this subject will allow for a better understanding of the issues presented in this paper as well as their practical use in the optimization of training of elite swimmers.

Conclusions

The results of the study allow the following conclusions to be drawn:

1. Increasing swimming velocity during the 200 m backstroke leads to an increase in glucose concentration in capillary blood. In order to obtain an almost linear relationship between glucose and lactate in a 5 × 200 m test, it is crucial to begin the test at an intensity that corresponds to a lactate concentration of less than 3.6 mmol · l^{-1}.
2. Significant correlations between lactate and glucose levels in blood were found in most of the performed test, where Spearman's correlation coefficient was frequently higher than 0.90.
3. The simultaneous monitoring of glucose and lactate levels in the blood during a lactate test can show at what exercise intensity the demand for glucose grows.
4. Decreased blood glucose concentration during a 5 × 200m backstroke test may indicate an increase in aerobic metabolism.

References

1. Bompa T.O., Periodization: Theory and methodology of training. 2nd Ed. Human Kinetics, Champaign 1999.
2. Heck H., Mader A., Hess G., Mucke S., Muller R., Hollmann W., Justification of the 4 mmol/l lactate threshold. *Int J Sports Med*, 1985, 6 (3), 117–130, doi: 10.1055/s-2008-1025824.
3. Denadai B.S., Figueira T.R., Favaro O.R.P., Goncalves M., Effect of the aerobic capacity on the validity of the anaerobic threshold for determination of the maximal lactate steady state in cycling. *Braz J Med Biol Res*, 2004, 37 (10), 1551–1556, doi: 10.1590/S0100-879X2004001000015.
4. Fontana P., Boutellier U., Knöpfli-Lenzin C., Time to exhaustion at maximal lactate steady state is similar for cycling and running in moderately trained subjects. *Eur J Appl Physiol*, 2009, 107 (2), 187–192, doi: 10.1007/s00421-009-1111-1119.
5. Fernandes R.J., Sousa M., Pinheiro A., Vilar S., Colaco P., Vilas-Boas J.P., Anaerobic threshold individualized assessment in a young swimmer. *Open Sport Sci J*, 2010, 3, 134–136.
6. Zinner C., Krueger M., Wahl P., Sperlich B., Mester J., Comparison of three different step test protocols in swimming. *J Exerc Physiol*, 2011, 14 (1), 43–48.

7. Pelayo P., Mujika I., Sidney M., Chatard J.C., Blood lactate recovery measurements, training, and performance during a 23-week period of competitive swimming. *Eur J Appl Physiol*, 1996, 74 (1/2), 107–113, doi: 10.1007/BF00376502.
8. Lormeau B., Sola A., Tabah A., Chiheb S., Dufaitre L., Thurninger O. et al., Blood glucose changes and adjustments of diet and insulin doses in type 1 diabetic patients during scuba diving (for a change in French regulations). *Diabetes Metab*, 2005, 31 (2), 144–151, doi: 10.1016/S1262-3636(07)70180-5.
9. Sideraviciūte S., Gailiūniene A., Visagurskiene K., Vizbaraite D., The effect of long-term swimming program on glycemia control in 14-19-year aged healthy girls and girls with type 1 diabetes mellitus. *Medicina*, 2006, 42 (6), 513–518.
10. Adolfsson P., Ornhagen H., Jendle J., Accuracy and reliability of continuous glucose monitoring in individuals with type 1 diabetes during recreational diving. *Diabetes Technol Therap*, 2009, 11 (8), 493–497, doi: 10.1089/dia.2009.0017
11. Bonomo M., Cairoli R., Verde G., Morelli L., Moreo A., Grottaglie M.D. et al., Safety of recreational scuba diving in type 1 diabetic patients: the deep monitoring programme. *Diabetes Metab*, 2009, 35 (2), 101–107, doi: 10.1016/j.diabet.2008.08.007.
12. Acevedo E.O., Meyers M.C., Hayman M., Haskin J., Applying physiological principles and assessment techniques to swimming the English Channel. A case study. *J Sports Med Phys Fitness*, 1997, 37 (1), 78–85.
13. Sengoku Y., Nakamura K., Takeda T., Nabekura Y., Tsubakimoto S., Glucose response after a ten-week training in swimming. *Int J Sports Med*, 2011, 32 (11), 835–838, doi: 10.1055/s-0031-1279778.
14. Sato A., Shimoyama Y., Ishikawa T., Murayama N., Dietary thiamin and riboflavin intake and blood thiamin and riboflavin concentrations in college swimmers undergoing intensive training. *Int J Sports Nutr Exerc Metab*, 2011, 21 (3), 195–204.
15. Hoogenboom B.J., Morris J., Morris C., Schaefer K., Nutritional knowledge and eating behaviors of female, collegiate swimmers. *N Am J Sports Phys Therap*, 2009, 4 (3), 139–148.
16. Maglischo E.W., Swimming even faster. Mayfield Publishing Company, Mountain View 1993.
17. Pyne D.B., Lee H., Swanwick K.M., Monitoring the lactate threshold in world-ranked swimmers. *Med Sci Sports Exerc*, 2001, 33 (2), 291–297.
18. Stavrianeas S., Stephenson A., Lactate testing revisited: a reliable indicator of training progress for all swimmers. *Int J Aquat Res Educ*, 2007, 1, 65–72.
19. Maughan R.J., Greenhaff P.L., Leiper J.B., Ball D., Lambert C.P., Gleeson M., Diet composition and the performance of high-intensity exercise. *J Sports Sci*, 1997, 15 (3), 265–275, doi: 10.1080/026404197367272.
20. Emhoff C.A.W., Messonnier L.A., Horning M.A., Fattor J.A., Carlson T.J., Brooks G.A., Gluconeogenesis and hepatic glycogenolysis during exercise at the lactate threshold. *J Appl Physiol*, 2013, 114 (3), 297–306, doi: 10.1152/japplphysiol.01202.2012.
21. Janssen P.G.J.M., Lactate threshold training. Human Kinetics, Champaign 2001.
22. Paschoal V.C., Amancio O.M., Nutritional status of Brazilian elite swimmers. *Int J Sport Nutr Exerc Metab*, 2004, 14 (1), 81–94.
23. Kabasakalis A., Kalitsis K., Tsalis G., Mougios V., Imbalanced nutrition of top-level swimmers. *Int J Sports Med*, 2007, 28 (9), 780–786, doi: 10.1055/s-2007-964907.

Paper received by the Editors: April 1, 2013
Paper accepted for publication: October 28, 2013

Correspondence address
Grzegorz Bielec
Zakład Pływania
Akademia Wychowania Fizycznego i Sportu
im. Jędrzeja Śniadeckiego
ul. Kazimierza Górskiego 1
80-336 Gdańsk, Poland
e-mail: pitajlo1@wp.pl