THE ROLE OF AEROBIC CAPACITY IN HIGH-INTENSITY INTERMITTENT EFFORTS IN ICE-HOCKEY

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ABSTRACT: The primary objective of this study was to determine a relationship between aerobic capacity ($\dot{V}O_2$max) and fatigue from high-intensity skating in elite male hockey players. The subjects were twenty-four male members of the senior national ice hockey team of Poland who played the position of forward or defence. Each subject completed an on-ice Repeated-Skate Sprint test (RSS) consisting of 6 timed 89-m sprints, with 30 s of rest between subsequent efforts, and an incremental test on a cycle ergometer in the laboratory, the aim of which was to establish their maximal oxygen uptake ($\dot{V}O_2$max). The analysis of variance showed that each next repetition in the 6x89 m test was significantly longer than the previous one ($F_{5,138}=53.33$, $p<0.001$). An analysis of the fatigue index (FI) calculated from the times recorded for subsequent repetitions showed that the value of the FI increased with subsequent repetitions, reaching its maximum between repetitions 5 and 6 ($3.10\pm1.16\%$). The total FI was $13.77\pm1.74\%$. The coefficient of correlation between $\dot{V}O_2$max and the total FI for 6 sprints on the distance of 89 m ($r=-0.584$) was significant ($p=0.003$). The variance in the index of players' fatigue in the 6x89 m test accounted for 34% of the variance in $\dot{V}O_2$max. The 6x89 m test proposed in this study offers a high test-retest correlation coefficient ($r=0.78$). Even though the test is criticized for being too exhaustive and thereby for producing highly variable results it still seems that it was well selected for repeated sprint ability testing in hockey players.

KEY WORDS: aerobic capacity, anaerobic capacity, intermittent exercise, ice-hockey

INTRODUCTION

Ice-hockey is a team sport where the players to demonstrate comprehensive physical fitness. To be able to compete on ice in a permanent physical contact with opponents, they must demonstrate high levels of speed, strength and endurance [4, 8, 28, 38]. Inherent to this sport are high-intensity intermittent efforts involved in starts, accelerations, stops, changes in skating direction, body checking or other manoeuvres [3, 22]. Depending on the player's position and style, the strategy of the game and coaching decisions each on-ice shift usually lasts between 30 and 85 s, interspersed with 2 to 5 min of recovery between shifts [8, 22]. Energy for high-intensity exercise of this duration is supplied by anaerobic metabolism, resulting in depletion of adenosine triphosphate phosphocreatine (ATP-PC) stores and a corresponding increase in inorganic phosphate, accumulation of H^+ ions, an increase in lactate formation, and a decrease in pH, while oxidative phosphorylization during rest periods is necessary to achieve sufficient recovery before initiating the next bout of work [12]. All these physiological mechanisms have been related to the development of fatigue and a decline in power output [5]. The challenge for the coach from the bioenergetics and

physiologic perspectives is to maintain the player's energy and skill levels throughout the game by using short shifts to avoid fatigue and providing adequate recovery time between shifts [23].

It is thought that the aerobic system may be of prime importance for a recovery process [9, 36, 40]. Tesch and Wright [35] have found a significant correlation between capillary density and blood lactate concentration, suggesting that an improved efflux of lactate results from increased capillary density. Harris [16] and Colliander [6] have showed that enhanced oxygen delivery to muscles post-exercise potentially accelerates the rate of PCr resynthesis, an oxygen-dependent process. Takahashi [36] has reported that trained runners have faster rates of phosphocreatine (PCr) resynthesis than untrained subjects, which should enhance subsequent performance. Hamilton et al. [15] has compared the aerobic response of endurance-trained runners ($\dot{V}O_2$max 60.8 ml·kg^{-1}·min^{-1}) and games players ($\dot{V}O_2$max 52.5 ml·kg^{-1}·min^{-1}) during repeated all-out 6 second treadmill sprints and has found that both groups attained similar peak power, but runners consumed significantly more oxygen during repeated intervals and demonstrated a significantly smaller percentage decrement in

power over the 10 sprints than did games players. McMahon and Wenger [21] have found a significant relationship (–0.62) between $\dot{V}O_2$max and a decrease in mean power in repeat cycle sprints. Karakoç et al. [19] have found in young soccer players significant negative relationships (–0.66) between peak power and FI measured in the Wingate anaerobic test and Yo-Yo intermittent recovery test level 2 performance. The study by Żebrowska et al. [41] showed a significant negative correlation (–0.95) between relative peak power obtained from the Wingate test and $\dot{V}O_2$max in female snowboarders.

It must be stressed, however, that some studies point to weak relationship, or even to a lack of significant relationships, between aerobic fitness and enhanced recovery from high intermittent exercise. Cooke [7] has reported that $\dot{V}O_2$max was a poor predictor of recovery from high intensity exercise and that $\dot{V}O_2$max did not correlate with PCr or phosphate recovery after 2 minutes of high-intensity exercise. Hoffman et al. [17] have found small, insignificant correlation coefficients (–0.26 and –0.24) between $\dot{V}O_2$max and FI in basketball players. Carey et al. [5] have established that the aerobic capacity of the group female collegiate hockey players measured by $\dot{V}O_2$max was not significantly related (r=–0.422) to their ability to recover from high-intensity exercise. The moderate correlations (–0.346 and –0.323) between $\dot{V}O_2$max and total time for 8 sprints found by Aziz et al. [1] led the authors to conclude that improving aerobic fitness would not be expected to greatly affect recovery from high-intensity exercise. All these studies indicate that the ability to perform maximally on repeated exercise bouts, most required in ice hockey, is closely related to anaerobic attributes such as muscle phosphocreatine degradation and muscle buffer capacity, and to aerobic qualities such as maximal oxygen uptake. Therefore, the primary objective of this study was to determine the relationship between aerobic capacity ($\dot{V}O_2$max) and fatigue from high-intensity skating in elite male hockey players.

MATERIALS AND METHODS

Subjects. The study participants were twenty-four male members of the national ice hockey team of Poland who played the position of forward or defence. Their mean ($\pm$SD) age was 25.2 $\pm$ 3.93 years, height 182.9 $\pm$ 3.7 m, and body mass 86.9 $\pm$ 6.1 kg. The study protocol conformed with the revised Declaration of Helsinki. The study design was approved by the Bioethics Commission of the Academy of Physical Education in Katowice. The subjects were advised about the study's possible risks and benefits and their consent to participate was received. Each subject was asked to get full night's sleep of at least 8 hours before the test, to abstain from using any substances for 48 hours before the test, and from taking any physical activity that might affect their physical or physiological reactions.

Experimental design

The study had two parts. In the first part, each subject completed the Repeated-Skate Sprint test (RSS) consisting of 6 timed 89-m sprints, with 30 s of rest between subsequent efforts [29]. Three

days later, at the same time of the day, the subjects performed an incremental test on a cycle ergometer so that their maximal oxygen uptake ($\dot{V}O_2$max) could be measured. The tests were performed at the end of the competitive season when the players were in peak condition, 2 weeks before the World Championships.

In the second part involving an on-ice test, subjects wearing full hockey equipment except for the stick performed 6 timed 89 m sprints at the highest velocity, with 30 s of a rest period between subsequent efforts. Before the test commenced, each subject carried out an individual 5 min warm-up with elements such as skating forward, skating backward, starts and stops. Each test sprint started at the goal line (Fig. 1). Having crossed the opposite goal line (54 m) with both skates the player would stop immediately and then skated back towards the blue line situated closer to the start line (89 m), the crossing of which ended the sprint. Exactly 30 s after he crossed the blue line the player would skate again. Photocells made by Microgate (Bolzano, Italy) recorded the times of each sprint with accuracy of 0.01 s, separately for the length between the start line and the opposite goal line (54 m) and between the latter and the blue line closer to the start line (35 m). Together with the time of the return, the two times consisted the total time of one sprint (89 m). The indicators were respectively FLS (the time of the first length skate) and TLS (the total time of the whole distance). Furthermore, a fatigue index (FI) was calculated from the following formula ((the fastest skate time – the slowest skate time)/the fastest skate time) x 100) [29].
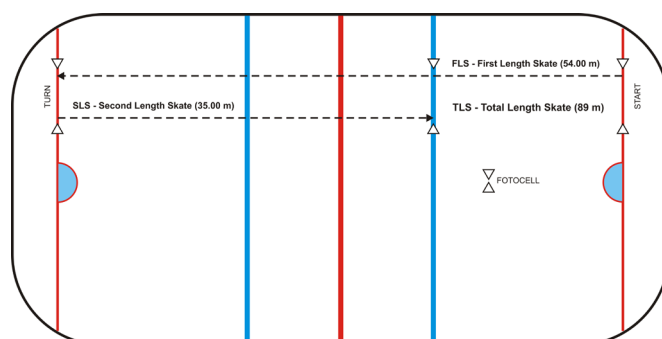

FIG. 1. THE REPEATED SKATE SPRINT (RSS) TEST.

A standard incremental maximal oxygen uptake test was conducted in the laboratory using open-circuit spirometry and computerized instrumentation. Each subject performed the test until voluntary exhaustion on a cycling ergometer platform Cyclus 2 (RBM elektronik-automation GmbH, Leipzig, Germany). Before the test commenced, the players warmed up on the ergometer for 5 minutes by riding steadily at a power level of 1 W·kg^{-1} after which exercise intensity was increased to 4 W·kg^{-1} for duration of 10 seconds. The first 3 minutes of the test involved exercise intensity of 1 W·kg^{-1} of body weight, which was then increased every 3 minutes by 0.5 W·kg^{-1} of body weight. Exhaled air was continuously sampled by a K4b2 gas analyser (Cosmed, Italy) and the rate of oxygen con-

sumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), and the respiratory exchange ratio (RER) were calculated every 5 seconds by an on-line computer system. The K4b2 was calibrated following the manufacturer's specifications at the beginning of each test day. The test was terminated on the subject's request or after the $\dot{V}O_2$max criteria were met (e.g. RER greater than 1.10 at test termination; oxygen consumption reaching a plateau or starting to fall even though the work rate kept increasing or the maximal age-specific heart rate was reached) [10, 20].

Statistical analysis

Descriptive statistics including mean ± standard deviations (SD) were calculated for each variable. All variables were examined for normal distribution. Differences between the durations of particular repetitions in the RSS test were established with the one-way analysis of variance (ANOVA). When significant differences in F ratio were found, the post-hoc Tukey's test was applied. The relationships between FI obtained from the RSS test and $\dot{V}O_2$max were determined with the Pearson's product-moment correlation analysis. The level of significance was set at 0.05 for all tests. Calculations were performed with the Statistica 10 statistical software package (StatSoft, USA).

RESULTS ■■■■■■■■■■

The results of the incremental maximal oxygen uptake test ($\dot{V}O_2$max test) are presented in table 1.

TABLE I. DESCRIPTIVE STATISTICS OF STANDARD INCREMENTAL MAXIMAL OXYGEN UPTAKE

Parameter	N	Mean±SD	CV	Min-Max	As	Ku
$\dot{V}O_2$max $(ml \cdot kg^{-1} \cdot min^{-1})$	24	58.75 ± 2.44	4.15	54 - 65	0.298	0.985

Note: SD=standard deviation; CV=coefficient of variation; As=skewness; Ku=kurtosis

Figure 2 represents graphically the times recorded for the first length skate (FLS, 54 m) during the 6x89 m test. As could be expected, the times increase with each subsequent repetition, pointing to players' growing fatigue. The analysis of variance showed significant differences between at least one pair of results obtained during subsequent repetitions ($F_{5,138}=70.53$, $p<0.001$). The upper section of Fig. 2 shows the results of the post-hoc Tukey's test, according to which each next repetition is significantly longer than the previous one. One exception is skate 6, the time of which is not significantly different from the time of skate 5. Figure 3 shows the total time of all repetitions (TLS, 89 m) obtained by the players. The analysis of variance yielded a significant F-Ratio ($F_{5,138}=53.33$, $p<0.001$). This time the follow-up pairwise Tukey's test indicated that every

next repetition was significantly slower than the previous one. The skating times and FI for subsequent FLS and TLS are presented in detail in table 2.
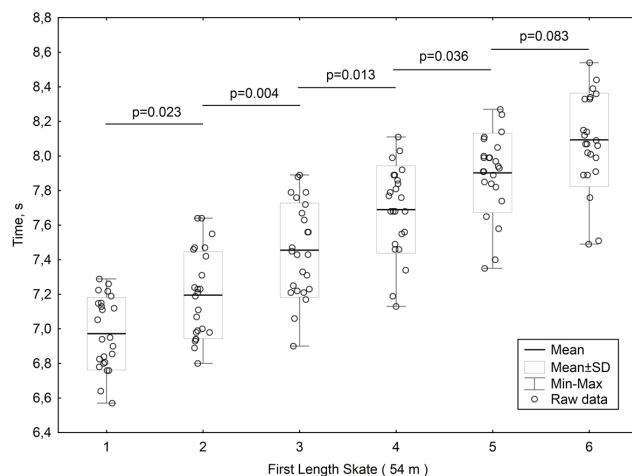

FIG. 2. RESULTS RECORDED FOR FLS (54 M) DURING SUBSEQUENT REPETITIONS OF THE 6X89 M TEST
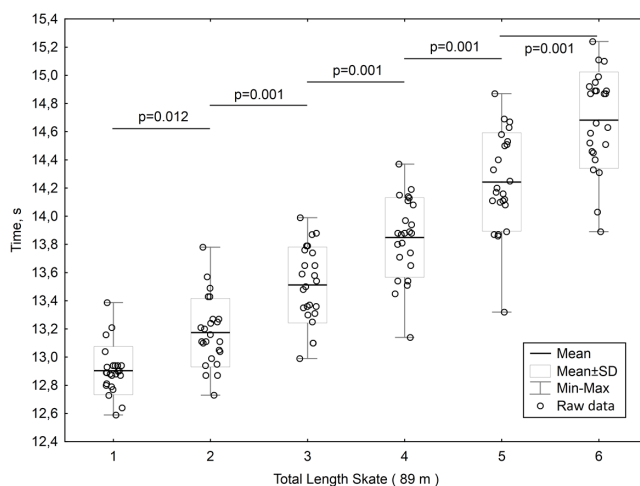

FIG. 3. RESULTS RECORDED FOR TLS (89 M) DURING SUBSEQUENT REPETITIONS OF THE 6X89 M TEST
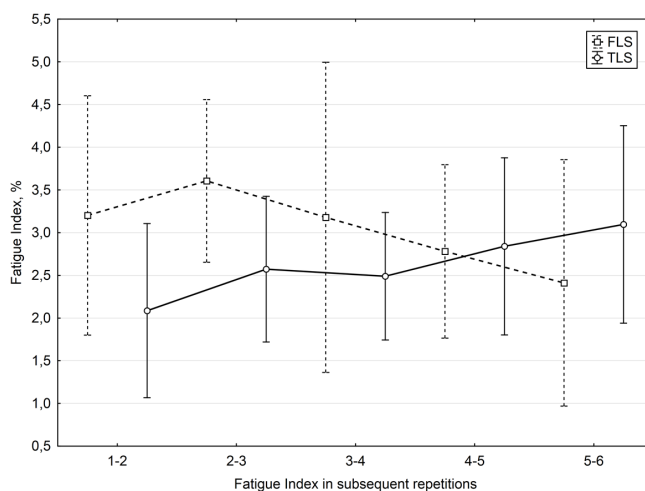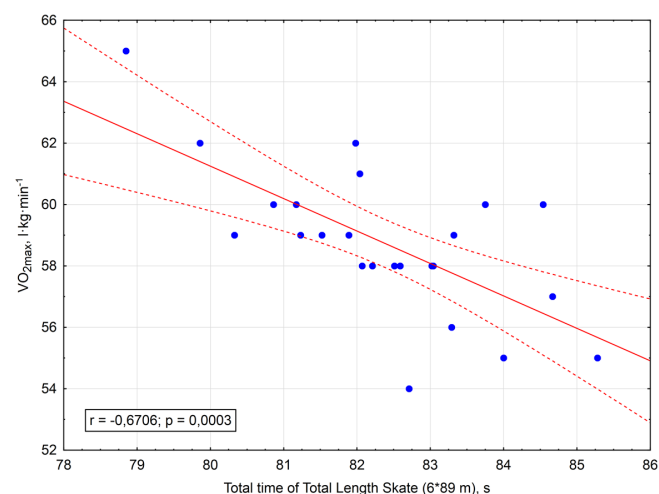

FIG. 4. FI RECORDED FOR SUBSEQUENT REPETITIONS OF FLS AND TLS

TABLE 2. THE FLS AND TLS TIMES IN THE 6X89 M TEST AND FI BETWEEN SUBSEQUENT REPETITIONS

	Skate 1	Skate 2	Skate 3	Skate 4	Skate 5	Skate 6
FLS (s)	6.97±0.21	7.20±0.25	7.46±0.27	7.69±0.25	7.90±0.23	8.09±0.27
FI_FLS (%)	3.20±1.40	3.61±0.95	3.18±1.82	2.78±1.01	2.41±1.44	
TLS (s)	12.90±0.17	13.17±0.24	13.51±0.27	13.85±0.28	14.24±0.35	14.68±0.34
FI_TLS (%)	2.09±1.02	2.57±0.85	2.49±0.75	2.84±1.04	3.10±1.16	

Note: FLS = the time of the first length skate; TLS = the total time of the whole distance; FI_FLS, FI_TLS = fatigue index calculated from the times recorded for subsequent FLS and TLS
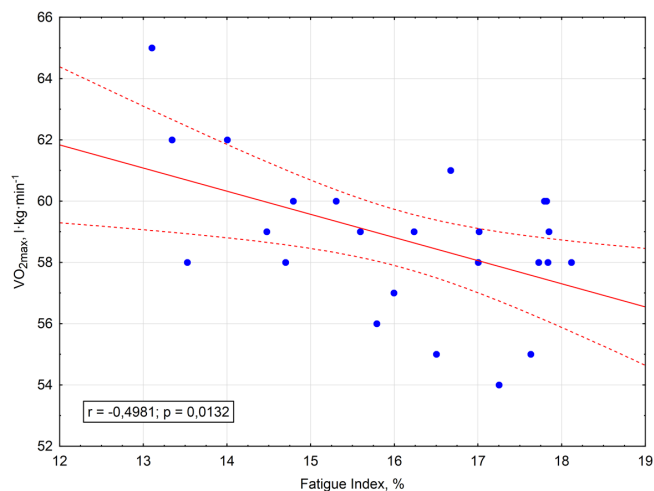
FIG. 5. A SCATTER PLOT OF CORRELATIONS BETWEEN $\dot{V}O_{2MAX}$ AND THE TOTAL FI AFTER 6 SPRINTS ON THE DISTANCE OF 54 M
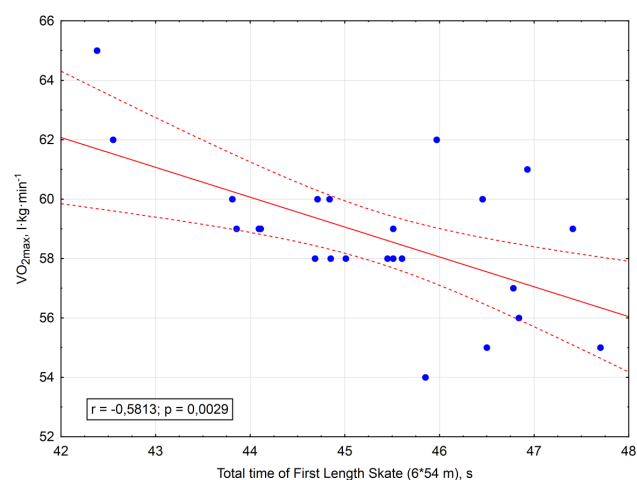
FIG. 7. A SCATTER PLOT OF CORRELATIONS BETWEEN $\dot{V}O_{2MAX}$ AND THE TOTAL TIME OF 6 SPRINTS ON THE DISTANCE OF 54 M
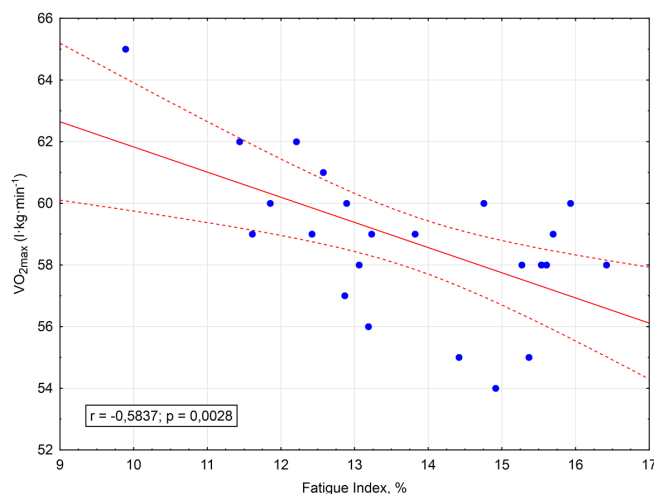
FIG. 6. A SCATTER PLOT OF CORRELATIONS BETWEEN $\dot{V}O_{2MAX}$ AND THE TOTAL FI AFTER 6 SPRINTS ON THE DISTANCE OF 89 M

FIG. 8. A SCATTER PLOT OF CORRELATIONS BETWEEN $\dot{V}O_{2MAX}$ AND THE TOTAL TIME OF 6 SPRINTS ON THE DISTANCE OF 89 M

An analysis of the FI (table 2) calculated from the times recorded for subsequent FLS showed its greatest value between repetitions 2 and 3 (3.61±0.95), and then the value was lower and lower between subsequent repetitions. The total FI calculated for repetitions 1 and 6 was 16.09±1.61%. The value of the FI for the TLS times increased with subsequent repetitions, reaching its maximum between repetitions 5 and 6 (3.10±1.16%). The total FI was 13.77±1.74%. The graphic representation of the FI for subsequent FLS and TLS are presented in figure 4.

Figures 5 and 6 show the relationship between total FI calculated as a percentage difference between the times recorded for sprints 1 and 6 on a distance of respectively 54 m (Fig. 5) and 89 m (Fig. 6) and players' $\dot{V}O_2$max measured during the incremental test on a cycle ergometer. The correlation coefficient (–0.498) is statistically significant (p=0.013), which means that the index of fatigue caused by six sprints explains only 24.8% of the variance in $\dot{V}O_2$max. The coefficient of correlation between $\dot{V}O_2$max and the total FI for 6 sprints on the distance of 89 m is higher (–0.584) and
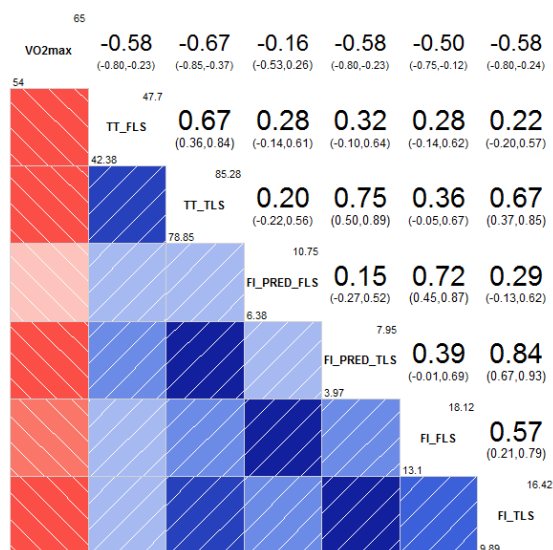
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FIG. 9. A CORRELOGRAM OF THE $\dot{V}O_{2MAX}$ AND RSS TESTS' RESULTS. Note: TT_FLS=total time for all 6 skates in first length skate; TT_TLS=total time for all 6 skates in total length skate; FI_FLS=fatigue index in first length skate; FI_TLS= fatigue index in total length skate; FI_PRED_FLS= fatigue index represents percent change from predicted times in first length skate; FI_PRED_TLS = fatigue index representing a percentage change from predicted times in total length skate;

also significant (p=0.003). The variance in the index of players' fatigue in the 6x89 m test accounts for 34% of the variance in $\dot{V}O_2$max. Figures 7 and 8 present relationships between the total time required to cover the distance 6x54 m (Figure7) and 6x89 m (Figure 8) and players' $\dot{V}O_2$max measured during the incremental test on a cycle ergometer. In both cases, the obtained correlation coefficients (r=–0.581 and r=–0.671, respectively) are statistically significant (p=0.003), what, by means of the $\dot{V}O_2$max, allows to explain in 33.8% and 45.0%, respectively, the variance of the total time required to cover the repeated distances of 54 m and 89 m.

Figure 9 shows the Pearson's moment-product correlation which illustrates relationships between $\dot{V}O_2$max and various RSS parameters.

DISCUSSION ▄▄▄▄▄▄▄▄

Ice hockey is a very complex team game, the final result of which depends on various factors [30, 32]. Most important are the player's skills in skating, an activity involving maneuverers such as starts, accelerations, sprints, rapid changes in skating directions or braking. Therefore, skating involves intermittent work, where maximal-intensity efforts of 3-5 seconds alternate with low-intensity efforts [8, 24, 27]. The improvement of skating speed, particularly in the context of multiple repetitions of actions, should be a focus of training and conditioning programs and a criterion measure for selecting athletes

to competitive teams [33]. This study was designed to evaluate the effect of aerobic capacity measured with the maximal oxygen uptake test ($\dot{V}O_2$max test) on the ability to skate over multiple short distances with maximal intensity.

The study allowed identifying a significant correlation was identified between aerobic capacity measured with $\dot{V}O_2$max and FI obtained during the 6x89 m test, for both the FLS (r=–0.498) and the TLS (r=–0.584). This result is consistent with the findings reported in many research papers on the same subject [6, 19, 21, 34, 35, 39]. The relationships between $\dot{V}O_2$max and the FI for repeated sprints found in this and the above studies seem to indicate that aerobic processes play a role in the recovery of energy substrates, which are necessary to exercise at high intensity. There are many mechanisms that can explain this results. Most of all, high aerobic power increases the ability to recover from repeated bouts of anaerobic power, and probably decreases lactate concentrations in response to higher LA utilization in slow twitch muscle fibres [35, 37]. Lactate removal from muscle is enhanced by increased buffering capacity and increased blood flow. Increased capillary density, as seen in endurance-trained individuals, provides a decreased diffusion distance between capillaries and muscle fibres, enhancing movement of oxygen and nutrients to, and the removal of H^+ and lactate from the muscle [18]. Enhanced oxygen delivery to muscles post-exercise potentially accelerates the rate of PCr resynthesis, an oxygen-dependent process [6, 13].

As mentioned in the introduction, the results obtained by some authors [1, 5, 7] do not confirm aerobic capacity to be significantly related to the results of the tests of high-intensity repeated sprint ability (RSA). It is therefore worth establishing why researchers arrive at results that are so different. The first factor that should be addressed is the variety of test variants, which differ in respect of sprint distance, the number of sprint repetitions and recovery duration, as well as the type of recovery [2, 11, 13, 30]. The next factors are the large number of approaches to processing and analysing the results of the RSA tests, as well as inappropriate methodological assumptions resulting in poor correspondence between the test and the actual demands of competition. This situation made Pyne et al. [26] conclude that one has to be cautious expressing RSA results, because this is sensitive to the method used for performance analysis. Glaister et al. [14] has demonstrated that among the various methods applied to measure high-intensity RSA the FI proposed by Fitzsimons et al. [11] is the most important and most reliable. FI is the percentage difference between the times of the fastest skate (usually the first one) and of the slowest skate (usually the last one). Pyne et al. [26] have compared different parameters used to assess RSA, taking into account also the total time of all repetitions and a FI calculated as a percentage difference between the total time (TT) of all repetitions and the predicted time determined by multiplying the time of the fastest skate by the number of repetitions (FI_PRED). Pyne's [26] research showed a strong relationship between TT and FI_PRED (r=0.91) and weak relationships between TT and FI (r=0.12),

and between FI and FI_PRED (r=–0.23). Consequently, Pyne et al. [26] concluded that the ability to perform repeated sprints was more closely related to maximal effort speed rather than shuttle test performance.

The Pearson's moment-product correlation presented in figure 9 shows relationships between $\dot{V}O_2$max and various RSS parameters. The relationship between $\dot{V}O_2$max and the total time for all six skates in the first length skate (TT_FLS) (r = –0.58) and the total length skate (TT_TLS) (r= – 0.67) is moderately negative. Unlike the results obtained by Pyne at al. [26], in this study a very strong correlation was found between fatigue indicators FI_FLS and FI_PRED_FLS and between FI_TLS and FI_PRED_TLS (r = 0.72 and r = 0.84, respectively). At the same time, the relationship between fatigue index FI_FLS and the total time of all six skates in the first length skate TT_FLS was weak (r = 0.28), while that between FI_TLS and TT_TLS was more pronounced (r = 0.67).

CONCLUSIONS

One of the main factors in designing a relevant protocol of the RSS test is the number of repetitions set to evoke a significant decrease in player's efficiency [11]. An RSA test that is too short will not induce the required fatigue state whereas extensive sprinting may induce pacing that can lead to redundant information and the likelihood of injury [31]. The 6x89 m test proposed in this study offers a high test-retest correlation coefficient (r = 0.78). Even though the test is criticized for being too exhaustive and thereby for producing highly variable results [25] it still seems that it was well selected for repeated sprint ability testing in hockey players.

Conflict of interest: the authors did not declare any conflict of interest.

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