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Prediction of Maximum Lactate Concentration During an All-Out Anaerobic Test in Elite Ice Hockey Players

MAXIME ALLISSE‡[1], HUNG TIEN BUI‡[2], PATRICK DESJARDINS‡[3], PHILIPPE ROY†[4], ALAIN-STEVE COMTOIS‡[4], and MARIO LEONE‡[2,3]

[1]Department of Kinanthropology, University of Sherbrooke, Sherbrooke, Québec, Canada; [2]Faculty of Medicine, University of Sherbrooke, Sherbrooke, Québec, Canada; [3]Department of Health Sciences, University of Québec in Chicoutimi, Saguenay, Québec, Canada; [4]Department of Exercise Sciences, University of Québec in Montréal, Montréal, Québec, Canada

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 16(4) 1385-1397, 2023. The lack of specific on-ice tests to predict maximum lactate concentration limits the ability of coaches to better track and develop their ice hockey players. Thus, this study aimed to develop an equation for indirectly assessing the maximum lactate concentration produced from an all-out on-ice skating effort in elite adolescent ice hockey players. Twenty elite male ice hockey players participated in this study (age = 15.7 ± 1.0 year). The lactate anaerobic skating test (LAST) consisted of skating back and forth on an 18.2 m course at maximal speed with abrupt stops at each end for a total of 6 shuttles (total distance = 218.2 m; average time = 52.0 ± 2.0 s). The oxygen uptake was measured using a portable metabolic analyzer (Cosmed K4b^2) and the maximum post-exercise lactate concentration with a Lactate Pro analyzer. The variables used to estimate lactate concentration were time, heart rate, number of skating strides in the last shuffle (6th) and the skating stride index. The average maximum lactate concentration was 14.4 mmol · L^{-1}, which is expected in elite players. The analysis of explained common variance using *T*-test (r^2 = 0.759) and linear regression (r^2 = 0.863) demonstrates the validity of the model. Additionally, the root mean square error (RMSE = 0.60 mmol · L^{-1}), the mean absolute error (MAE = 0.45mmol · L^{-1}) and the standard error of estimate (SEE = 0.69 mmol · L^{-1}) values further confirm the accuracy of the model. Thus, using simple and easy-to-measure variables (i.e., time and skating stride), coaches will be able to monitor more effectively their players' progress in an effort to optimize their individual on-ice performance.

KEY WORDS: Oxygen cost, skating efficiency index, physiologic assessment, maximal effort, anaerobic efficiency

INTRODUCTION

The assessment of physical fitness in high performance athletes requires the consideration of multiple factors that may influence athletic performance. In fact, ice hockey requires skills that are very specific to the on-ice game context, and for which the off-ice fitness assessment is only marginally transferable to the on-ice performance (4, 26, 31). These constraints, as well as the advent of more sophisticated technologies, allow strength and conditioning specialists and/or researchers to rethink the on-ice fitness assessment. Although some devices that measure metabolic parameters such as blood lactate level or oxygen consumption are much more affordable today, the fact remains that their cost of purchase, exploitation and maintenance remain a barrier to a widespread use of these products. Therefore, in order to facilitate the accessibility of this type of data in a user-friendly manner, it becomes important to develop field tests that make it possible to obtain this type of information. While several field tests have been developed to estimate the efficiency of the aerobic system for either general application (8, 10, 17) or for sport-specific use (2, 7, 15, 19, 25), the counterpart concerning the anaerobic system is much less common. Indeed, as far as we know, only one test can indirectly estimate the maximum lactate concentration (30). However, since this test takes place on an ergometer bicycle according to the Wingate protocol, the specific aspect of ice hockey is not present.

In 1991, a research group led by Larivière (14) presented an on-ice field test that required 6 all-out back and forth shuttles (stop and go) over an 18.2 m course (typically, blue line to blue line). This validated test (content validation) lasting approximately 50 seconds demonstrated that it has excellent reliability by displaying a test-retest correlation coefficient of r = 0.96. Although the concept of this test is interesting because of its nature and specificity, it only provides the execution time (s) as an index of anaerobic performance. On the other hand, Allisse et al., (1) recently presented a series of four on-ice anaerobic field tests that estimate the oxygen cost during different skating situation. However, these tests, although relevant in some respect, do not provide any estimation about the maximum lactate level that can be reached by the players.

Many authors have raised that ice hockey, because of its intermittent and high intensity nature, requires a significant contribution from the anaerobic system that typically leads to an important lactate accumulation, as observed during games (6, 9, 13, 16, 22, 28). Thus, it is generally accepted that the amount of lactate accumulated may influence ice hockey performance. Indeed, since the level of lactate can be affected by the state of training and the level of fatigue (28, 29) its regular assessment can contribute to better supervise the player's physical fitness. In addition, a significant relationship has also been demonstrated between the concentration of lactate and the degradation of the technical qualities of the hockey players, which will also have a negative impact on the performance on ice (22). It therefore seems rather clear that such information could be extremely useful in order to optimize players' training program, and eventually, on-ice performance.

Thus, the goal of this study was to develop an algorithm that would allow predicting the blood lactate concentration following an all-out on-ice maximal effort using the lactic anaerobic skating test (LAST).

METHODS

Participants

A convenience sample of 20 male elite ice hockey players participated in this study. All participants were exclusively selected from a sport-study program that recruits the most talented U15 and U17 players from the Saguenay area in Québec, Canada. Efforts were made to reach out to club officials to evaluate their willingness to participate in our study. Subsequently, we established communication with the respective coaches, who expressed their keen interest in participating to this project. The skating test was conducted on a regular Canadian ice rink (61 m long × 26 m wide) just before the beginning of the hockey season (end of September). Although the players came from different hockey teams, they trained as a group five days/week between August and March. Prior to the beginning of the study, each participant and their parents signed an informed consent form as it was required from the hockey direction board for the student/player to be included as participants in the hockey program. The project was approved by the University Institutional Ethical Committee Board (no: 602.391.01). This manuscript followed the instructions set out in the article recommended by the journal (23).

Protocol

Anthropometric variables (weight, height and body mass index) were collected using the procedure proposed by Lohman et al. (20). Anthropometric measurements were performed in the first week of September, always in the morning in order to control for the effect of the circadian cycle. Body mass (BM) was noted to the nearest 0.1 kg using a Detecto scale (Missouri, USA). Body height (BH) was assessed using a Lafayette stadiometer (Louisiana, USA) to the nearest 0.1 cm. Estimation of the body fat composition was performed by bioelectrical impedance (Tanita, model TBF-300A, Illinois, USA). In order to control the hydration rate, each assessment was done in the evening, outside the training sessions. Participants were instructed not to eat and/or drink 3 hours before the test, not to drink coffee and/or alcohol 12 hours prior to the test, not to perform excessive exercise 24 hours before the test, and lastly to empty their bladder 30 minutes before the test. Finally, body mass index (BMI) was calculated using the following formula: $BM \cdot BH^{-2}$ where BM represents body mass (kg) and BH the body height (m).

The LAST was evaluated in agreement with the procedures recommended by Larivière et al. (14) and more recently by our group (3, 5). The LAST consisted of skating 6 back and forth shuttles on an 18.2 m (roughly blue line to blue line) course at maximal speed with abrupt stops at each end. Players had to wear their complete hockey gear during the LAST which when completed represented a total skating distance of 218.4 m (12 × 18.2 m).

A user-friendly skating stride efficiency index (SSI_6) was calculated by dividing the number of skating strides at the last back-and-forth shuttle by the average speed ($strides \cdot m^{-1} \cdot s^{-1}$) required to complete the LAST course. This SSI_6 is based on the research of Allisse et al. (1, 2) and was included in the regression model to predict the maximum blood lactate level.

Oxygen uptake (VO_2peak) was assessed using a portable metabolic analyzer system (Cosmed K4b^2, Rome, Italy). The data were recorded by telemetry. Oxygen uptake values were calculated using the software program provided by the manufacturer (Cosmed version 10A, Rome Italy). The system calibration was carried out before each test using ambient air (20.93% O_2 and 0.03%

CO_2) and a calibration gas having 17.00% O_2 and 5.03% CO_2. The airflow at the mouth turbine was calibrated with a 3-L syringe.

Blood lactate concentration $[La^+]_b$ was measured using a portable lactate analyzer (Lactate Pro-LT-1710, Kyoto, Japan), using compatible strips provided by the manufacturer, as well as lancets (Accu-Chek Safe-T-Pro Plus), alcohol swabs (Paramedic), sterile compresses (Formedica), medical gloves (AMD Ritmed), sterile dressings (Equate) and a medical waste container (Fisherbrand, 2 gallons Infectious Waste Container, Lot #: 00163140, Cat No. 22037959). Immediately after the end of the LAST, the player glided towards the players' bench (without extra effort) and sat in order to take the blood drop samples at 1, 3, 5, 10 and 15 minutes (essential for the production of post-exercise lactate kinetics). The lactate pro LT-1710 device used in this study has been previously validated by McNaughton and colleagues (21).

The time for each on-ice event was measured using wireless photocells (Brower timing system, model CM15 MEM, Utah, USA). Total time was recorded to the nearest 0.01 second. In addition, each player was filmed throughout the test. This procedure has been added in order to review the number of skating strides or to re-time the performance in the event of a malfunction of the timing system. This alternative has already been shown to be valid by Leone et al. (18).

Heart rate (HR) was measured by telemetry using the T-31 400 Polar heart rate belt (Polar, Kempele, Finland). Similarly, to the oxygen uptake, the HR was measured continuously until the end of the procedure.

Statistical Analysis

All descriptive values are reported as medians, means ± standard deviations (SD). The Shapiro-Wilk test for normality was performed for each variable and Q-Q plots were produced to detect outliers. All variables of interest were normally distributed (see Supplementary material for details). Confidence intervals (CI) were set at the level of 95% limits of agreement. The regression equations were calculated using standard linear regression procedure. Standard error of estimate (SEE), standard error of the mean (SEM), mean absolute error (MAE), root mean square error (MRSE), correlation coefficients (r) and coefficient of determination (r^2) were also computed. The Bland-Altman analysis was used to compare measured and predicted lactate values. Reference values were calculated based on scores corresponding to the 25th, 50th and 75th percentiles. A power exponential method, which smoothed the curves by cubic splines (a cubic polynomial curve of degree 3), has been used to create the curves. The level of significance was set at $p \leq 0.05$. Statistical analyses were performed using the IBM SPSS V24.0 software.

RESULTS

All anthropometric variables are presented in Table 1. All players belonged to teams playing in the U17 and U15 elite leagues.

Table 1. Anthropometric characteristics of the players.

Variables	Mean ± SD	95% CI	Median
Age (Years)	15.7 ± 1.0	15.3 - 16.2	16.1
Body mass (kg)	68.1 ± 8.9	64.0 - 72.3	67.9
Body height (cm)	174.1 ± 5.8	171.4 - 176.8	173.3
BMI ($kg \cdot m^{-2}$)	22.4 ± 2.3	21.3 - 23.5	22.8
% fat	14.6 ± 4.6	12.4 - 16.7	15.0

BMI = Body Mass Index; SD = Standard Deviation; CI = Confident interval

Figure 1 presents various physiological and skating characteristics in elite ice hockey players. Figure 1A shows that the skating speed decreases rapidly as time increases (Figure 1B) with cumulative back and forth shuttles. Figures 1C and 1D indicate that O_2 uptake in $ml \cdot kg^{-1} \cdot min^{-1}$ or in $L \cdot min^{-1}$ (VO_2peak) increases until about the 5th shuttle and then decreases (i.e., after 35-40 seconds of maximal effort). Figure 1E illustrates that the SSI (number of skating strides at a given shuttle divided by the speed at the same shuttle) increases with the number of shuttles, thus highlighting a decrease in skating efficiency. Finally, Figure 1F shows that the heart rate rises rapidly and then tends to stabilize from the 5th shuttle, thus indicating that the effort is maximum.

Figure 2 shows the relationship between skating speed and selected physiological and skating variables. Thus, Figure 2A indicates that the higher the speed, the higher the SSI, indicating a loss of skating efficiency. The relationship between the skating speed and the VO_2peak curves is illustrated in Figures 2B and 2C. The aerobic contribution decreases rapidly with increasing skating speed whether VO_2peak is expressed in relative or absolute values. Figure 2D shows the relationship between maximum post-exercise $[La^+]_b$ production and maximum skating speed. Consequently, the higher the skating speed, the higher the maximum $[La^+]_b$ concentration. It should be noted, however, that maximum $[La^+]_b$ values tend to peak around 15 $mmol \cdot L^{-1}$ (typical for elite ice hockey players). Figure 2E shows that for most players, the maximum $[La^+]_b$ concentration measured post-exercise is reached around the 5th minute after the end of the test.

Figure 3 is the Bland-Altman plot showing the agreement between the measured lactate values and the values predicted by our model. Furthermore, the p-value of 0.495 indicates the absence of proportional bias between both data sets.

Table 2 compares maximum $[La^+]_b$ concentration from measured to predicted values. The predicted value is almost identical to the measured value with a strong correlation coefficient of $r = 0.871$ ($r^2 = 0.759$) and a small standard error of the mean (SEM) of 0.32. Although there is a significant difference for age between the youngest and oldest group ($p = 0.001$), no significant difference is observed for the maximum $[La^+]_b$ values between the two groups ($p = 0.248$). Thus, the results from both age groups can be combined into one single group without affecting the internal and external validity of the lactate prediction outcome.

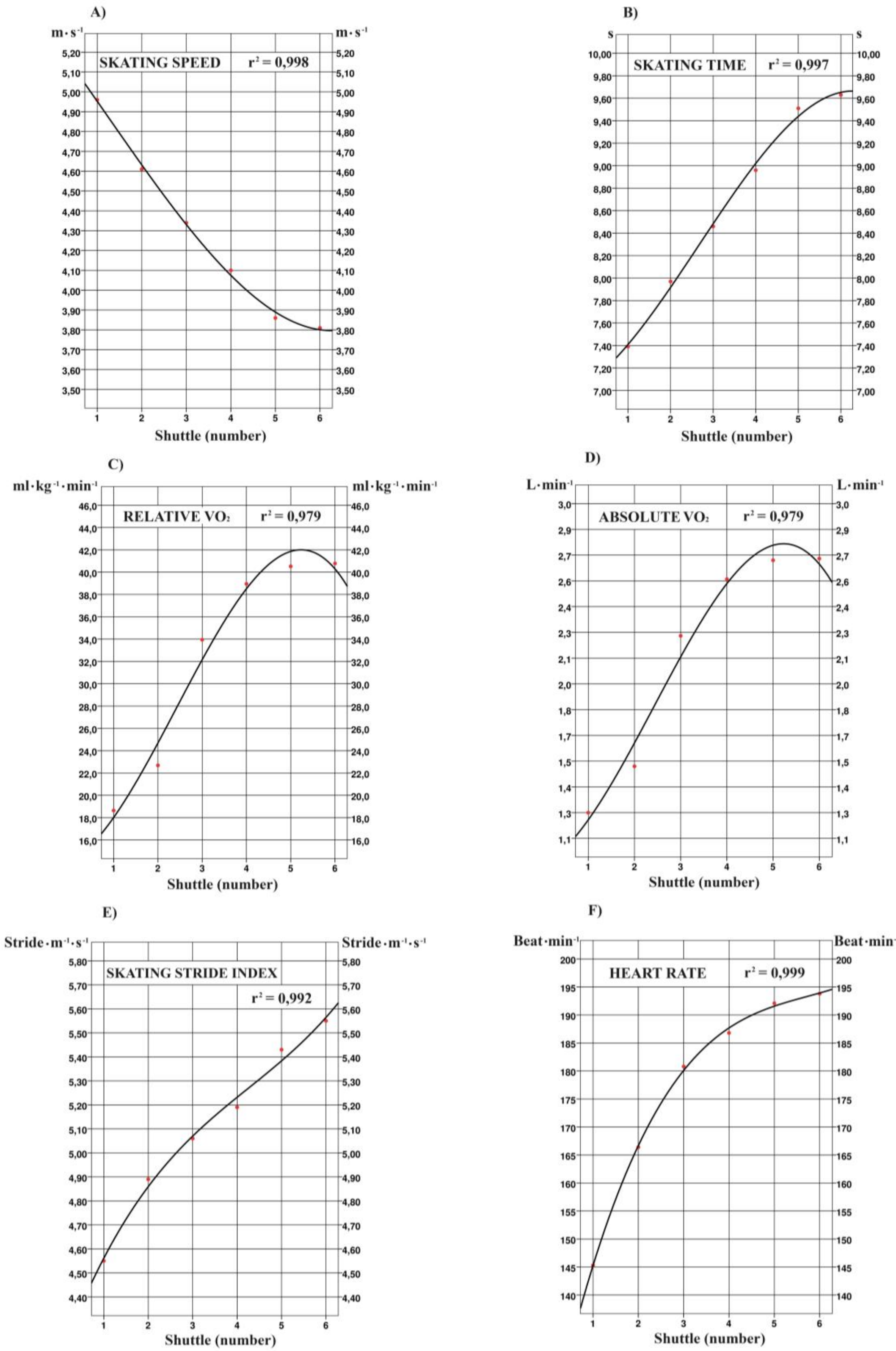

Figure 1. Modeling of skating performance curves based on the 6 back and forth shuttles for skating speed (1A), time (1B) relative VO_2 (1C), absolute VO_2 (1D), Skating Stride Index (1E) and maximum heart rate (1F). Each data point in the graph corresponds to the average value for the corresponding back and forth shuttle

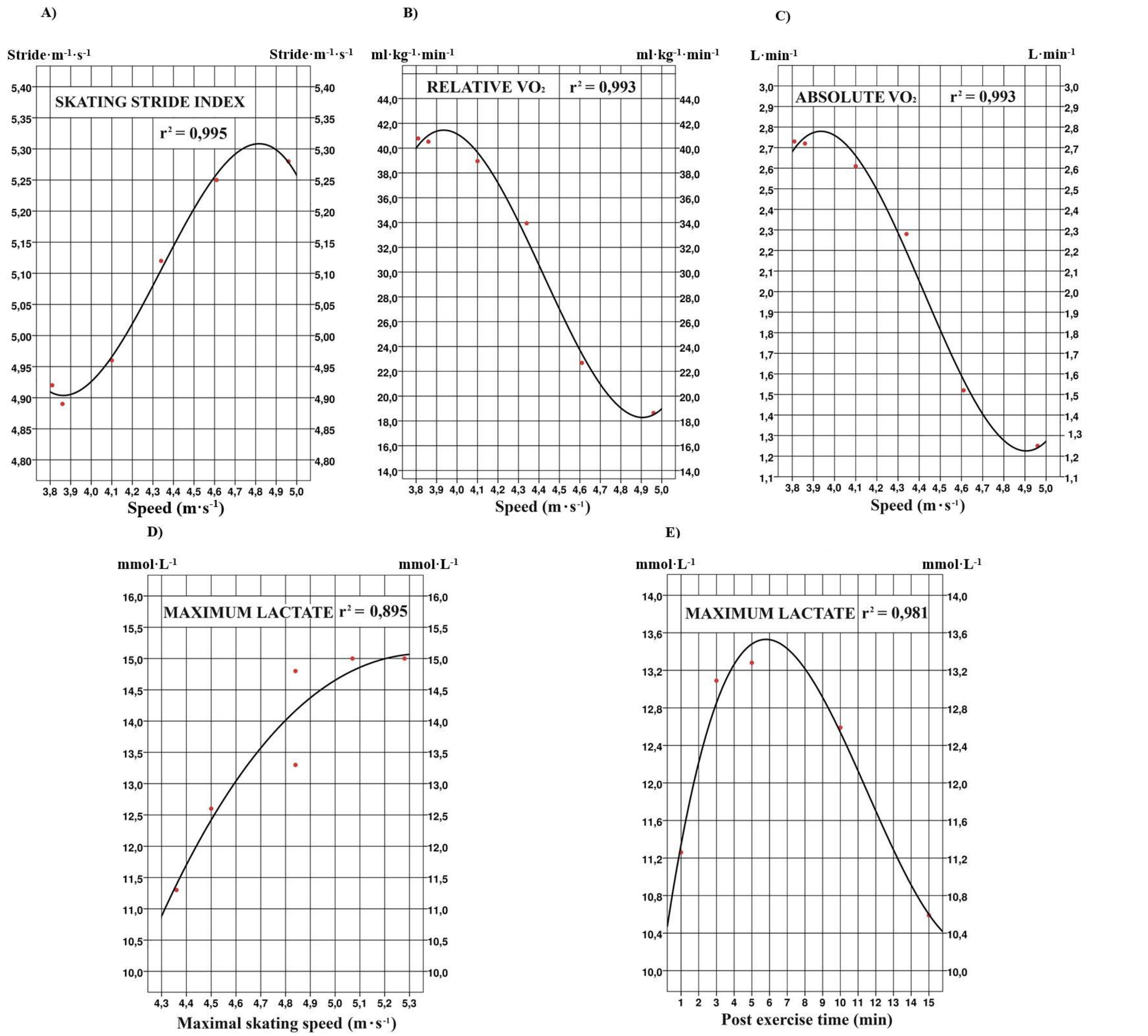

Figure 2. Modeling of skating performance curves based on skating speed for Skating Stride Index (2A), relative VO_2 (2B), absolute VO_2 (2C), maximum lactate concentration (2D) and post exercise dynamic recovery of maximum lactate concentration (2E). Each data point in the graph corresponds to the average value for the corresponding back and forth shuttle except for Figure 2E.

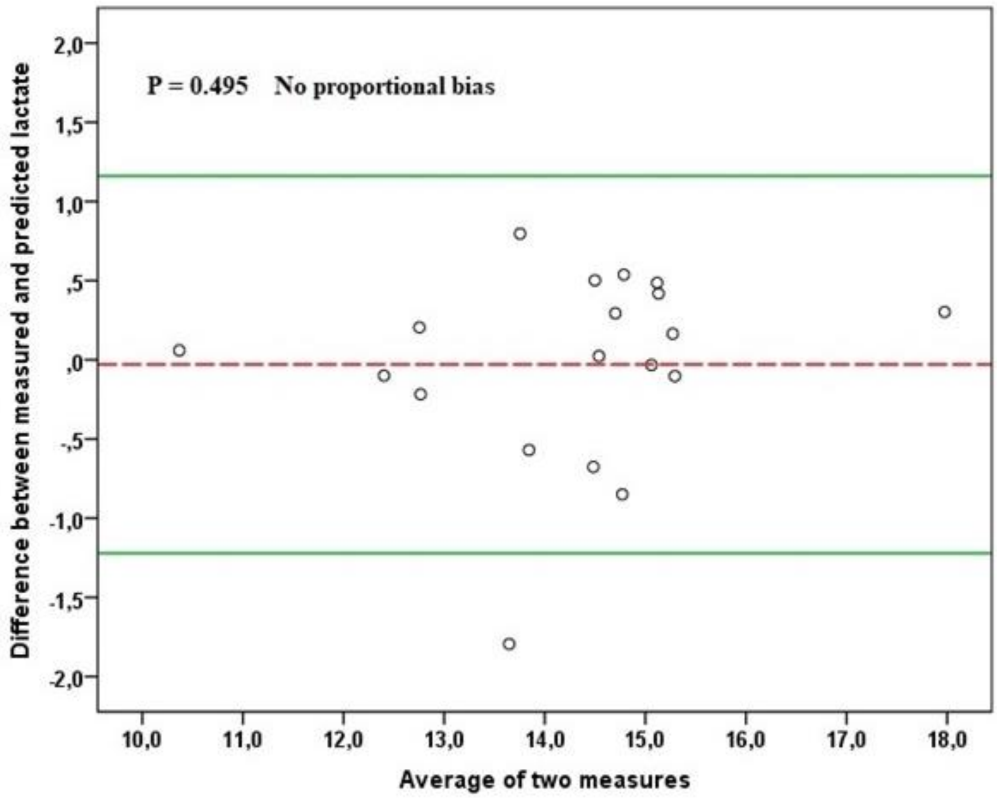

Figure 3. Bland-Altman plot comparing the measured versus the predicted values of the lactate concentration at the end of the all-out anaerobic test (LAST). The two green lines represent the confident interval (CI95%) and the red dashed line represents the mean of the differences between the two compared methods of measurements.

Table 2. Comparison between the maximum measured and predicted lactate concentration (mmol · L^{-1}) between younger and older players for age and the measured maximum lactate concentration.

	n	Mean ± (SD)	CI	SEM	*p*-value	r^2
Measured maximum lactate (mmol · L^{-1})	20	14.5 ± 1.4	13.6–15.1	0.32	0.346	0.759
Predicted maximum lactate (mmol · L^{-1})	20	14.7 ± 1.2	14.1–15.2	0.28		
Age						
Younger players (years)	10	15.0 ± 0.7	14.5–15.5	0.22	0.001	N/A
Older players (years)	10	16.5 ± 0.6	16.1–16.9	0.17		
Lactate concentration						
Younger players (mmol · L^{-1})	10	13.9 ± 1.7	13.7–15.9	0.53	0.248	N/A
Older players (mmol · L^{-1})	10	14.8 ± 1.5	12.7–15.1	0.48		

SD = Standard Deviation; CI = Confident Interval; SEM = Standard Error of the Mean; p = Significant at $p \leq 0.05$; r^2 = Coefficient of determination

Table 3 shows the linear regression equation that has been used to develop the algorithm for the prediction of maximum $[La^+]_b$ concentration. On the basis of four simple variables (time, heart rate, number of skating strides on the 6th back and forth shuttle and the SSI), an excellent correlation coefficient of $r = 0.929$ ($r^2 = 0.863$) is obtained with a standard error in the estimate (SEE) of 0.69, which is quite acceptable for a field test. The model's accuracy was assessed by evaluating the RMSE (0.60 mmol · L^{-1}) and MAE (0.45 mmol · L^{-1}) values, both of which indicate a high level of accuracy for the model. In addition, a second regression equation excluding skating variables is also included to demonstrate the effect of these factors on the accuracy of the prediction of the estimated maximum $[La^+]_b$ concentration. With a correlation coefficient of r = 0.485 (r^2 = 0.235) and a SEE of 1.51, the importance of including skating efficiency variables appears unequivocal in order to optimize the model. In order to facilitate the calculation, an Excel file has been created. To use it, just enter the total time, the number of skate strides during the last shuttle (6^{th}) and the maximum heart rate at the end of the test to obtain all the results (see Supplementary materials).

Table 3. Regression equations to predict lactate level from the LAST.

Skating lactate level estimation	r^2	RMSE	MAE	SEE
Lactate (mmol·L^{-1}) = – 161.88 + (Time 218.2 m × 3.10) + (stride_6 × 8.36) + (HR × 0.064) + (SSI × −34.51)	0.863	0.60	0.45	0.69
Skating lactate level estimation without skating variables				
Lactate (mmol·L^{-1}) = (Time 218 m × −0.28) + (HR × 0.08) + 13.90	0.235	1.51	1.11	1.51

Time 218.2 m = the time needed to cover the 6 back and forth shuttle totaling a distance of 218.2 m during the test; stride_6 = the stride of the 6th back and forth shuttle; HR = the heart rate at the end of the test: SSI = the number of skating strides at the last back and forth shuttle, divided by the average speed (strides · m^{-1} · s^{-1}) to complete the LAST course, r^2 = coefficient of determination

Table 4 presents reference values (percentile ranks) for the physiological and skating variables. Although this table contains also some variables that are not included in the regression equation, this additional information allows coaches to obtain a more comprehensive picture of the players' profile.

Table 4. Physiological, skating characteristics and centile scores for ice hockey players

	VO_2relative (ml · kg^{-1} · min^{-1})	VO_2absolute (ml · kg^{-1} · min^{-1})	HRmax (Beat · min^{-1})	SStotal (nb)	Time (s)	Speed (m · s^{-1})	SS_6 (nb)	SSI (SS_6 · m · s^{-1})	Lactate (mmol · L^{-1})
Mean	43.0± 4.5	2.9±0.4	195.0± 10.3	129.9± 7.9	52.0± 2.0	4.3± 0.2	21.0± 1.7	4.9± 0.4	14.4± 1.6
25^{th} centiles	40.7	2.6	186.0	123.0	49.9	4.1	20.0	4.6	13.1
50^{th} centiles	42.5	2.9	195.0	129.5	52.6	4.2	21.0	4.9	14.7
75^{th} centiles	44.7	3.3	205.0	134.0	53.7	4.5	22.0	5.3	15.4

SD = Standard Deviation; HRmax = Maximum heart rate; SStotal = Total skating stride (218.2m); Time = Total time (218.2 m); Speed = Average speed (218.2 m); SS_6 = Skating stride at shuttle 6

DISCUSSION

The goal of this study was to develop an algorithm that would allow estimating the maximum $[La^+]_b$ concentration following an all-out on-ice maximal effort (LAST). The much greater accessibility of advanced technologies enables the development of field assessment tools that are more powerful and accurate than ever before. It is now easier to validate procedures that are transferable to the field because of simplicity of use and low cost to increase the possibility of adoption by coaches. To our knowledge, there is no specific ice hockey field test to estimate the maximum $[La^+]_b$ production in a purely anaerobic test, which is quite surprising given the importance of this metabolic pathway in a sport such as ice hockey.

The LAST is an interesting test in several respects. The fact that it takes place on-ice enables the criterion of specificity that is often missing with this type of test. Its maximum nature ensures that anaerobic glycolysis is stressed to its full potential. This is confirmed by the fact that, at the end of the test, more than 95% of the maximum HR was reached (HR = 195.0 ± 10.3 $beat \cdot min^{-1}$). Moreover, the duration of the effort lasting about 50 s, corresponds roughly to the duration of a presence on ice during a game. Finally, the LAST requires a series of sprints punctuated by stops and starts that are also an integral part of the actions experienced during a hockey game.

VO_2peak was assessed to determine the oxygen cost during the LAST. The measured values indicate that the exerted effort does not fully meet the energy demands solely through the aerobic process. The obtained values (43.0 ± 4.5) are considerably lower than the previous reported VO_2max values (53.6 ± 3.0) for similarly skilled younger players (3). Additionally, Figure 1C clearly depicts a plateau followed by a decline in VO_2peak around the 5^{th} back and forth shuttle (approximatively 35-40 seconds of maximal effort), suggesting that the intensity exceeds the capacity of the aerobic system to sustain this level of effort.

During the test, we notice that the oxygen uptake increases as skating speed decreases. This phenomenon is logical since for the highest speeds, the aerobic system is unable to provide the oxygen necessary to maintain the effort. This phenomenon is observed from the 40th second (5th back and forth shuttle) while the oxygen uptake reached its maximum and then decreased. However, with the decrease in skating speed, a portion of the oxygen debt is repaid, which allows recycling part of the circulating lactate and thus restore the energy sources required to repeat other maximum efforts (12). In this regard, the increased ability to produce high lactate levels can be very beneficial to the hockey player. Indeed, in addition to recycled lactate at lower skating speeds, more of the lactate clearance will also occur between the on-ice shifts. The greater the amount of the lactate produced, the greater the potential for reforming new energy sources (24).

According to Di Prampero and Ferretti (11), the production of 1 $mmol \cdot L^{-1}$ of lactate is equivalent to approximately 3.3 $ml \cdot O_2 \cdot kg^{-1} \cdot min^{-1}$. Thus, it is worth noting the excellent agreement between the measured VO_2peak in this study and the predicted VO_2peak values based on the Di Prampero and Ferretti formula, confirming the accuracy of the present model. Therefore, the ability to produce a higher maximum concentration of lactate will give the player a clear advantage. Indeed, each presence on the ice will be performed at a higher intensity and duration, and this, throughout the game.

Allisse et al. (1) have recently shown from a series of on-ice anaerobic tests, the importance of considering skating efficiency in order to estimate anaerobic performance. Several years earlier, Saltin et al., (27) had also raised this point for activities that require preponderantly energy produced from the anaerobic system. In general, it is known that the higher the technical efficiency, the greater the energy saving (movement economy). In ice hockey, this can lead to lower energy expenditure at the same skating speed for the best skater (skating economy). This is particularly true for predominantly aerobic efforts when the speed is constant and submaximal (2). However, when the task requires generating maximum speed and maintaining it for as long as possible, the skating efficiency will deteriorate. This will lead to cause a greater lactate production, as we have demonstrated. Thus, the higher the skating speed, the greater the number of skating strides increase, especially in situations involving many stops and starts. The most desirable compromise is therefore to sacrifice some skating efficiency in order to achieve the highest possible speed. To be able to repeat this skating pattern often throughout a match, it will therefore be necessary to have players capable of producing larger lactate concentration. It is therefore important to include an index of skating effectiveness in training monitoring.

In order to verify this point, the variables directly related to the skating efficiency in the lactate prediction equation were removed (i.e., SSI_6 and Strides_6) and caused the correlation coefficient to drop from $r = 0.926$ ($r^2 = 0.858$) to $r = 0.485$ ($r^2 = 0.235$) and the SEE to increase from 0.69 to 1.5 $mmol \cdot L^{-1}$ (Table 3). This corresponds to an SEE of 10.4% which represents a 2.2 fold increase in the error of the estimate. Hence, the inclusion of skating variables significantly improves model accuracy, confirming the relevance of including skating economy variables for estimating maximum lactate level. In order to validate our model, we added the Mean Absolute Error (MAE) of 0.45 and the Root Mean Squared Error (RMSE) of 0.60, confirming that the model with more terms performs better. It is worth noting that for an indirect test, an estimation error below 5% is considered excellent.

This study is subject to certain limitations. There are a limited number of participants, and that requires conservative deductions. Furthermore, the sample included only individuals aged between 14 and 17 years. Although the proposed model works fine for this age group, it may be less efficient for younger or older players. Finally, even though the group of players was part of the elite in their respective age categories, it is not certain whether the model will be effective for higher level players (i.e., Junior Hockey League, AAA elite teams, etc.). It should be noted that in order to generalize these results to other levels and age groups, obtaining specific data for these categories is necessary. The equation presented in this study is indeed valid for players who possess the described characteristics. However, for players belonging to different levels or age groups, it is advisable to have specific data for those groups. Further research could also evaluate a larger sample, allowing the inclusion of other variables such as players' level and age, with the aim of obtaining a single equation.

This study allows the possibility for coaches to be able to associate some metabolic values during an on-ice test that involve the solicitation of the anaerobic lactic system. The short time required and the simplicity of the required variables make the use of this test attractive. Its validity as well as its reliability makes it a tool of choice for the evaluation of metabolic expenditure of the players. The results obtained will allow coaches to better target the needs of their players and thus improve their specific physical preparation.

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