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Original Article

Analysis of age-related changes of anaerobic power in ice hockey

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Abstract:
The purpose of this non-randomized cross-sectional study was to assess anaerobic power using the Wingate anaerobic test among youth and senior ice hockey players.The participants included 76 ice hockey players who were divided into three subgroups. Subgroup G1 included 30 senior players (aged ≥ 20.0 years), and subgroup G2 included 23 under-20-year-old players (aged 18.0 to 19.99 years). Subgroup G3 included 23 under-18 players who were aged 16.0 to 17.99 years. In the season during which anaerobic power testing was conducted, most of the players played for the top senior ice hockey teams on a regular basis. Off-ice anaerobic power was assessed by the Wingate anaerobic test using the Monark 894E weight brake cycle ergometer. The statistical significance of age category-related differences for parameters related to the anaerobic power of the ice hockey players was determined using the results of a one-way analysis of variance (ANOVA 1x3) with subsequent multiple comparison of means by an LSD post hoc analysis. The rejection of the null hypothesis was assessed at the level of $p < .05$. Effect size was determined using Cohen's "d" coefficient. The results showed that anaerobic capacity was statistically different according to age, and, in terms of practical significance, there was a large effect of age on the anaerobic parameters. There were neither a statistically nor practically significant difference in the parameters of anaerobic power and capacity between senior players and U20 players with the exception of the absolute values of peak anaerobic power.The results show that bicycle ergometer may be used to assess lower-body anaerobic power, but for ice hockey norm-referenced databases need to be modified for the AirBike.
KeyWords*:* **Wingate test, sports games, off-ice, season**

Introduction

Physical fitness can be assessed through 5 major components: cardiorespiratory endurance, muscular power/strength, muscular endurance, flexibility, and body composition. An anaerobic activity is defined as energy expenditure that uses anaerobic metabolism that lasts less than 90 seconds, utilizing an exhaustive effort. In a study by Zupan et al. (2009),the classification categoriesformulated will allow coaches, clinicians, and athletes to usethese charts as tools to evaluate power output and providecomparisons from a set of reliable standards. This informationshould begin to create a framework by which athletes cancompare their performance on the Wingate Anaerobic Test (WAnT).Anaerobic power is a significant predictor of acceleration and top speed in team sport athletes (Peterson et al., 2016; Fort-Vanmeerhaeghe et al., 2016; Manou, Aguilera, &Dalamitros, 2019;Tatlisu et al., 2019; Boraczyński et al., 2020). Historically, these findings have been applied to ice hockey although recent research has brought their validity for this sport into question. As ice hockey emphasizes the ability to repeatedly produce power, single bout anaerobic power tests should be examined to determine their ability to predict on-ice performance (Peterson et al., 2016).Ice hockey is a physiologically complex sport involving both the anaerobic and aerobic energy systems (Leiter et al., 2018). The physiological profiles of players have changed over time, with increases in body mass, body height, strength, and aerobic and anaerobic fitness (Montgomery, 2006; Quinney et al., 2008). In addition, the game is rough, often requiringintense physical contact, aggressive play and exercise intervals at maximal capabilities (Cox et al., 1995). In ice hockey, exercise intervals alternate with rest intervals depending on the game situation. From a physiological point of view, players engage in interval exercise without a precise exercise to rest ratio. In terms of physical conditioning, ice hockey players primarily rely on explosive strength, speed endurance, and strength endurance, which require anaerobic muscle metabolism (Helešic, 2009). Maximizing aerobic and anaerobic energy systems is essential for on-ice skating performance. For coaches, gaining an understanding of an individual player's overall capacity and development of these energy systems can be obtained through on-ice testing and possibly through select off-ice tests that may be more specific to evaluating the energetics of skating (Janot et al., 2015). More detailed investigations of strength, anaerobic and aerobic performance, and body composition in relation to skating performance may be obtained by conducting laboratory testing (Gilenstam et al., 2011; Henriksson et al., 2016). Researchers have identified anaerobic power as a key factor in predicting a team sport athlete's velocity and acceleration on the field (Pienaar & Coetzee, 2013). The most frequently used test to measure anaerobic capacity

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and power is the WAnT, which provides information about peak and mean anaerobic power and fatigue index (Leiter et al., 2018; Moroščák et al., 2013; Potteiger et al., 2010; Roczniok et al., 2016). Anaerobic readiness evaluated by a 30-s Wingate test may be, besides evaluating dominant on-ice skills, one of the criteria for entry into the top world ice hockey competition (Heller, Vodička, &Janek, 2019; Nightingale et al., 2013), because it is a statistically significant variable in a multivariate model for future success (Burr et al., 2008). In a study by Kokinda (2015),during a three-year observation period, the age of 27 years seems to be crucial in terms of progressive speed and strength development. Various training contents during the summer indicate content variability, which in the long-term was progressive in terms of the development of speed and strength of players. The purpose of our study was to assess anaerobic power using the Wingate anaerobic test among youth and senior ice hockey players.

Material & methods

Participants

This study is a nonrandomized cross-sectional study based on a retrospective analysis. The participants included 76 ice hockey players who were divided into three subgroups. Subgroup G1 included senior ice hockey players (*n* = 30) who played for clubs that advanced to the play-offs during a particular season (aged ≥ 20.0 years). Subgroup G2 (*n* = 23) included players, who, according to the Slovak Ice hockey federation rules, were U20 ice hockey players (aged 18.0 to 19.99 years). In the season during which the anaerobic power testing was conducted, most of the players played for top senior ice hockey teams on a regular basis. Subgroup G3 included under-18 players (*n* = 23) who were aged 16.0 to 17.99 years. The goalkeepers were not included in the study due to their specific on-ice roles, and especially because the anaerobic performance of goalkeepers corresponding toWAnT plays a minor role. In this particular season, all players played for elite Slovak youth or senior ice hockey teams. The analysis did not include goalkeepers and players who played for foreign ice hockey teams. A more detailed description of the sample is provided in Table 1.

Table 1. Description of the subgroups of ice hockey players in this study

Age group	n	Age (years)	BM (kg)	BH (cm)	BFP (%)
		Mean ± SD (min/max)			
Senior (G1)	30	25.9±3.9 (20.3/35.5)	90.3±9.2 (69.9/111.4)	183.2±5.6 (173.0/195.0)	14.2±3.7 (6.7/23.0)
U20 (G2)	23	18.8±0.9 (17.0/20.1)	85.4±12.2 (57.0/110.4)	183.3±6.4 (171.0/196.0)	12.1±4.3 (7.0/21.7)
U18 (G3)	23	15.8±0.6 (15.2/16.8)	71.6±8.0 (59.6/91.8)	177.6±5.6 (166.3/187.5)	13.6±4.0 (6.0/23.4)

Note. BM: body mass; BH: body height; PBF: body fat percentage.

Test protocol

Before the players completed the Wingate test, we measured their body heights and body masses. We used a SECA 217 portable stadiometer (Medical Measuring Systems and Scales, Hamburg, Germany) to measure body height to the nearest 0.1 cm. We subsequently measured their body masses and body compositions using the direct segmental multi-frequency bioelectric impedance analysis (DSM-BIA) on an InBody 720 body composition analyzer (Biospace Co., Ltd.; Soul, Korea) in line with standard conditions referred to in the bioimpedance analysis guidelines (Kyle et al., 2004). Using the Wingate anaerobic test (WAnT) on the Monark 894E weight brake cycle ergometer (Monark Exercise,Vansbro, Sweden), we assessed off-ice anaerobic power. The course and assessment of the WAnT test was conducted using Monark Anaerobic test software - version 3.0.1, which was supplied with the cycle ergometer.

The WAnT, which is a 30 s all-out test of anaerobic power, was conducted according to the testing protocol described by Gullstrand and Larsson (1999). Mechanical braking resistance equaled 7.5% of the participant's body mass, or 0.075 kg per kg of body mass within a 0.1-kg resolution of resistance range (Zupan et al., 2009). Power values were recorded in Watts and normalized for body weight. According to Patton et al. (1985), reliability of these measures, PP and MP, have been established as robust in this measurement setting ($r = 0.92$).For every participant, seat height was adjusted to a comfortable position so that the knee was slightly bent when the sole of the foot was centered over the pedal axle with the pedal in the bottom position. Participants performed a warm-up consisting of 5 min of pedaling with a frequency between 60 and 80 RPM and a mechanical resistance corresponding to 1-kg of weight. In the second phase of the specific warm-up, participants performed two 5-s pre-starts that were separated by 2 min of slow pedaling without loading. All participants were verbally instructed and encouraged to pedal as fast as possible (with maximal effort), and the entire test was conducted in the seated position.

Data collection and analysis /Statistical analysis

The descriptive statistical characteristics include the arithmetic mean and standard deviation for basic anthropometric parameters: body height, body mass, and body fat percentage. Of the directly aggregated software characteristics, we selected the parameters of absolute power (W) and relative power calculated relative

to each tested person's body mass($W.kg^{-1}$). To evaluate the off-ice anaerobic power, we used the following parameters: peak power in milliseconds (PP_{ms}) as the greatest power production during the test; peak power (PP_{5s}) as the greatest power production in any 5-s interval, and mean power (AvgP) as the mean power production sustained throughout the 30 s. These basic data were used to calculate the parameters of anaerobic capacity, which included: total work (AnC) computed according to the formula [(AvgP*test duration) / body mass] and fatigue index (%) calculated according to the formula [$((PP_{5s} - MinP_{5s}) / PP_{5s})*100$] to evaluate the decline in power during the test expressed as a percentage of peak power (Bar-Or, 1987). The collected data were subjected to statistical analysis and effect size analysis. The normality of data distribution was evaluated using the Shapiro-Wilk test. The statistical significance of age-related differences for the parameters of anaerobic performance of the ice hockey players was determined using results of a one-way analysis of variance (ANOVA 1x3) with a subsequent multiple comparison of mean by LSD post hoc analysis. The rejection of the null hypothesis was assessed at the level of $p \leq 0.05$. Effect size was determined using Cohen's "d" coefficient, which was calculated as the difference of the means of the individual groups of data divided by the pooled standard deviation (Thomas & Nelson, 2001). Effect size was estimated according to Cohen (1992) as follows: d > 0.2 - small effect size; d > 0.5 - medium effect size; d > 0.8 - large effect size.
Participants received a verbal description of the study procedures before testing and completed a written informed consent. This study was approved in advance by the Ethics Committee of the University of Presov. The procedures presented were in accordance with the ethical standards on human experimentation and in compliance with the Helsinki Declaration. Each participant voluntarily provided written informed consent before participating (Harriss& Atkinson, 2011).

Results

Table 2 shows the results of our comparative analysis of off-ice anaerobic power as a function of the age of the ice hockey players.

Table 2. Anaerobic power of ice hockey players relative to age

	Age group	Mean	SD	min/max	One Way ANOVA		LSD multiple Comparisons		
					F	p		p	*d*
PP_{ms} [W]	G1	1139.2	167.9	824.0/1431.9	23.658	0.001	G1/G2	0.059	small
	G2	1062.9	131.9	841.9/1321.7			G1/G3	0.001	large
	G3	869.1	118.0	722.3/1195.9			G2/G3	0.001	large
PP_{ms} [$W.kg^{-1}$]	G1	12.6	1.1	10.7/15.0	2.929	0.060	G1/G2	0.950	small
	G2	12.6	0.9	10.6/14.8			G1/G3	0.030	medium
	G3	11.9	1.2	10.2/15.0			G2/G3	0.048	medium
PP_{5s} [W]	G1	1016.4	137.3	731.7/1281.9	23.306	0.001	G1/G2	0.038	medium
	G2	940.7	127.5	747.4/1162.6			G1/G3	0.001	large
	G3	774.1	119.4	604.0/1062.4			G2/G3	0.001	large
PP_{5s} [$W.kg^{-1}$]	G1	11.2	0.9	9.5/12.6	3.332	0.041	G1/G2	0.892	small
	G2	11.2	1.0	9.2/13.1			G1/G3	0.020	medium
	G3	10.6	1.1	9.1/13.9			G2/G3	0.038	medium
AvgP [W]	G1	818.9	101.1	645.1/1043.4	20.711	0.001	G1/G2	0.119	small
	G2	776.8	103.6	568.7/977.7			G1/G3	0.001	large
	G3	650.2	82.0	490.7/834.6			G2/G3	0.001	large
AvgP [$W.kg^{-1}$]	G1	9,1	0,6	8.2/10.3	1.282	0.284	G1/G2	0.466	small
	G2	9.0	0.6	8.0/10.2			G1/G3	0.338	small
	G3	8.9	0.7	7.0/10.2			G2/G3	0.115	small
AnC [$J.kg^{-1}$]	G1	271.9	16.6	245.5/308.6	0.056	0.946	G1/G2	0.786	small
	G2	273.8	17.9	241.6/306.4			G1/G3	0.770	small
	G3	273.9	37.8	210.3/320.1			G2/G3	0.984	small
FI [%]	G1	42.5	6.1	30.7/54.0	10.386	0.001	G1/G2	0.455	small
	G2	41.2	5.5	30.1/49.3			G1/G3	0.001	large
	G3	35.0	6.8	32.2/49.5			G2/G3	0.001	large

Note.PP_{ms}: peak power observed in ms; PP_{5s}: peak power observed in 5s intervals; AVG P: average anaerobic power; AnC: anaerobic capacity; FI: fatigue index; G1: subgroup of senior age players; G2: subgroup of U20 players; G3: subgroup of U18 players

One-way ANOVA revealed significant age-related differences in the peak power (PP_{ms}) and peak power in the first 5-s interval of the WAnT (PP_{5s}). These differences were significant for both absolute and relative values of anaerobic power calculated relative to body mass. The LSD post-hoc test revealed significant differences (*p<.05) in all anaerobic power parameters between the senior ice hockey players and U20 ice hockey players compared with the U18 category. When assessing practical significance, we found that the age of the ice hockey players had a great effect on the absolute values of anaerobic power (d > 0.8). Regarding the relative values of peak anaerobic power, we found a medium effect of age (Table 2). The age of the ice hockey players had a significant effect on their anaerobic capacityparameters, especially on the average anaerobic power (AvgP) and fatigue index (FI). The parameters of average anaerobic power and fatigue index were significantly different between U18 players and senior players as well as between U18 players and U20 players. The effect size values showed a great effect of age (Table 2). There were neither statistically significant nor practically significant differences in the parameters of either anaerobic power or anaerobic capacity, with the exception of the absolute values of peak anaerobic power (PP_{5s}). We found that age had a medium effect on the absolute values of peak anaerobic power, and the differences were statistically significant (*P<0.05).

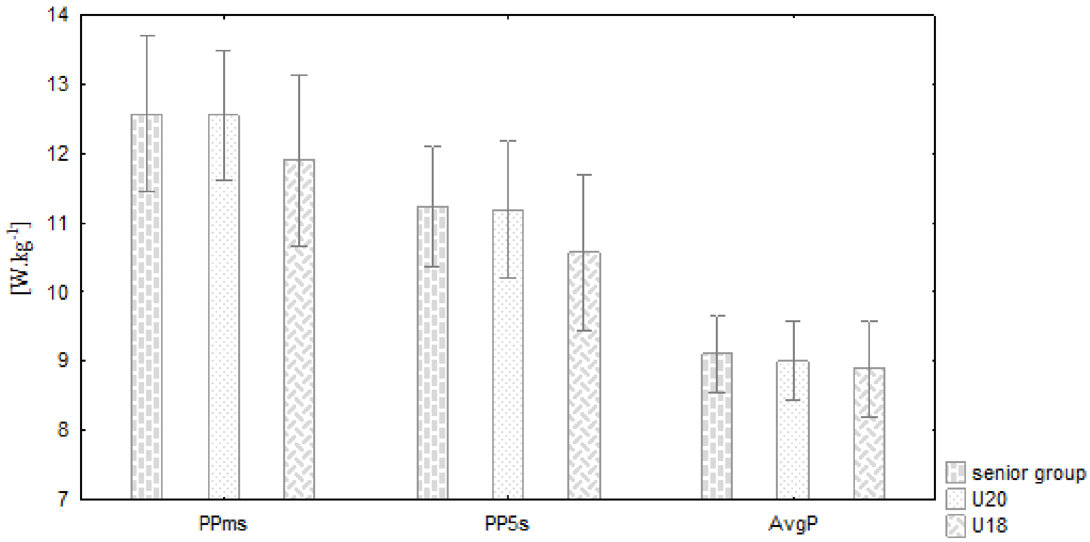

Figure 1. Anaerobic power relative to body mass

Discussion

Under-18 and under-20 age categories were more homogeneous in terms of age because the players have to follow competition rules. Higher level of variance was found in the senior category, which included players between 20.3 and 35.5 years of age. This shows that the U18 age category is the most important one with respect to anaerobic conditioning and transition to senior ice hockey. The demands placed on players are approach those placed on senior players, but the physical conditioning levels of young players do not meet the requited criteria of senior ice hockey. There are many physical and physiological changes that occur in top-level competitive male hockey players. Having a better understanding of how these athletes develop could aid the implementation of specific on- and off-ice training programs (Cordingley et al., 2019). The main finding of the present study was that both peak and mean anaerobic power increase with age. The differences in anaerobic parameters may be attributed to maturation and to the frequency, type, and volume to training undertaken by players of various ages.

In ice hockey, which may be defined as a power sports game, peak performance achieved during the first 5 s is a decisive factor in making fast skating strides. More significant differences were found in $PP_{ms,}$ PP_{5s},and AvgP, which were interpreted in absolute values (Table 2). Regarding the peak power achieved during the entire test, the differences among categories varied from 76.3 W to 270.1 W, especially in the U18 and senior categories. In the WAnT, it is decisive to achieve peak values during the first 5-s interval, during which performance differences observed varied from 75.7 W to 242.3 W. Under-18 players showed lower values of fatigue index compared with U20 and senior ice hockey players. This showed higher levels of aerobic conditioning than anaerobic conditioning. This is consistent with the trend recorded in terms of absolute values of average anaerobic power during the entire 30-s interval. The differences varied from 42.1 W to 168.7 W. If the values are adjusted for body mass, the differences minimize within the range between 0.1 and 0.7 $W.kg^{-1}$ (Figure 1).

In a study by Delisle-Houde (2019), the Wingate relative peak power was significantly correlated with on-ice forward skating and agility. Potteiger et al. (2010) found that players with the quickest skating times had the greatest percent fatigue, producing the greatest peak power per kg body mass during the Wingate test. In a study on the effect of age on anaerobic capacity in junior and senior ice hockey players, Gabrys et al. (2007) observed no significant differences between U20 players and seniors. However, there were significant increases in peak power and a significant reduction in time to peak power between U16 and U18 players. These findings are consistent with our results as we did not find any statistical differences between U20 players and their senior counterparts. On the contrary, the differences between U18 and U20 and senior ice hockey players were statistically significant. As reported by Gabrys et al. (2007), the results of their study showed that a long-term, short-interval training program performed by ice hockey players improves their anaerobic capacity. Differences in anaerobic power of ice hockey players were also confirmed by other studies as well. A study by Leiter et al. (2017) showed that relative peak and mean anaerobic power increased between the ages of 13 and 14 and 14 and 15 but not between the ages of 15 and 16 years old. There were no changes in fatigue index between any successive age groups, and anaerobic power increased with age with no associated change in fatigue index. Szmatlan-Gabrys et al. (2006) found that peak power output attained during the Wingate test was 13.84 ± 0.90 W/kg in senior ice hockey players, which was significantly higher than that attained by U16 and U18 players.

There was no difference in peak power output between senior players and U20 players, but the peak power output in U20 players was significantly higher in comparison to both U16 and U18. As reported by Heller et al. (2019), the relative values of peak power for senior national-level ice hockey players was 14.38 $W.kg^{-1}$, which shows that this mean value was significantly higher than that reported in our study. In their study conducted on members of the U16, U18, U20 and Polish senior team, Socha et al. (2006) found that the greatest differences occur in total work performed during the 30-secondWingate test. The hockey players from the U16 group performed onaverage approximately 29% less work, and U18 players performed approximately 20% less work than U20 players. There were also significant differences between particular age groups in maximal anaerobic power. For this variable, during the Wingate test, the worst results were achieved by hockey players from the youngest group (average of 78% of senior achievements). Regarding strength development, ice hockey coaches first design strength training sessions for U15 players. The sessions include technical drills and bodyweight exercises. Progressive resistance training is performed in the U18 category. Thus, our findings may be attributed to these strength training practices. The findings related to the anaerobic power parameters may aid coaches in tailoring training according to fitness levels and age groups.

Conclusions

The results of this study revealed significant age-related differences in peak power and peak power during the first 5-s interval of the Wingate test. These differences were significant for both absolute and relative values of anaerobic power calculated relative to body mass. There were significant differences in all anaerobic power parameters between the senior ice hockey players and U20 ice hockey players compared with the U18 category. When assessing practical significance, we found that the age of ice hockey players had a great effect on the absolute values of anaerobic power. Regarding the relative values of peak anaerobic power, we found a medium effect of age. The ice hockey players'age had a significant effect on theanaerobic capacityparameters, especially on the average anaerobic power and fatigue index.

The average anaerobic power and fatigue index were significantly different between U18 players and senior players as well as between U18 players and U20 players. The effect size values demonstrated the considerable effect of age. There were neither statistically significant nor practically significant differences in the parameters of either anaerobic power or anaerobic capacity, with the exception of the absolute values of peak anaerobic power. We found that age had a medium effect on the absolute values of peak anaerobic power, and the differences were statistically significant.Anaerobic capacity was statistically different according to age, and, in terms of practical significance, there was a large effect of age on anaerobic parameters.

There were neither a statistically nor practically significant difference in the parameters of anaerobic power and capacity between senior players and U20 players with the exception of the absolute values of peak anaerobic power. When training off the ice, ice hockey players often work out onAirBike, which enables them to perform whole-body proportional exercise compared with the bicycle ergometer. Therefore, it seems appropriate to modify and update norm-referenced criteria using exercise bikes that will meet the requirements of anaerobic workload performed by ice hockey players.

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