International Journal of EXERCISE SCIENCE

Review Article

Ice Hockey Goaltender Physiology Profile and Physical Testing: A Systematic Review and Meta-Analysis

VIVIANE MARCOTTE-L'HEUREUX†[1], JEREMIE CHARRON†[1], ROBERT PANENIC‡[2], and ALAIN STEVE COMTOIS‡[1]

[1]Department of Physical Activity Sciences, University of Quebec-Montreal, Montreal, Quebec, CANADA; [2]Department of Health, Kinesiology, and Applied Physiology, Concordia University, Montreal, Quebec, CANADA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(6): 855-875, 2021. This review aims to 1) be the first systematic review and meta-analysis of the literature examining the physiology and assessment of goaltenders, and 2) present a physiological profile of ice-hockey goaltenders. It will 1) highlight physiological differences between goaltenders and players at other positions, 2) determine strengths and weaknesses of ice hockey goaltenders, and 3) offer possible guidelines for strength and conditioning coaches. Six electronic databases were systematically searched in October 2019 using the PRISMA model. A total of twelve scientific articles published in peer-reviewed journals were included. Professional male (PM) goaltenders had the following profile for age (A) 26.8 ± 2.5 years, body weight (BW) 85.64 ± 3.79 kg, height (H) 184.38 ± 2.79 cm, body fat % (BF%) 11.9 ± 2.22, VO_2max 49.9 ± 4.45 ml/kg/min, anaerobic power (AP) 12.78 ± 1.63 W/kg, and combined hand grip strength (GS) 120.7 ± 15 kg. Amateur male (AM) goaltenders presented the following: A: 18.2 ± 0.75, BW: 83.85 ± 4.51, H: 184.96 ± 2.06, BF%: 10.51 ± 1.61, VO_2max: 55.73 ± 4.57, AP: 10.9 ± 1.2 and GS: 109.08 ± 14.06. Amateur female (AF) goaltenders presented the following: A: 21.04 ± 1.84, BW: 63.4 ± 5.14, H: 164.86 ± 5.73, BF%: 22.12 ± 2.27 and VO_2max: 42.84 ± 3.59. Overall, PM goaltenders are heavier, have a higher BF%, and exhibit greater GS and abdominal muscular endurance than AM, while AM goaltenders are heavier, taller, leaner, and can generate greater lower-body muscular power than AF goaltenders. In the current literature, there were a small number of studies on women players and a lack of distinction between player position in reported results. Specific physiological assessments during NHL Combines should be developed for goaltenders in accordance with their specific positional demands.

KEY WORDS: Assessment, fitness, performance, goalkeeper

INTRODUCTION

Physical, neuropsychological, physiological, and anthropometrical differences between ice hockey players, based on their positions, have been studied several times over the years by using a wide array of protocols. It has been shown that forwards and defenders have different physiological demands due to skating distance, on-ice time, and the amount of high-intensity skating per min required by their position (39, 45). Nevertheless, most of the investigations have focused on differences between these two positions while neglecting goaltenders because of their different role and positional demands (5, 9, 10, 18–20, 27, 31, 41, 53, 63, 65, 68, 74). Thus, the current scientific literature presents limited data on goaltender specific characteristics. To the best of our knowledge, no systematic reviews have been done on ice hockey goaltenders. Such a review would provide novel information to develop specific study designs to measure physiological characteristics in this group of highly specialized hockey players.

According to the scientific literature, the total game time for ice hockey players, excluding goaltenders, is approximately 15 to 25 minutes, depending on the position of the player (15, 43, 49, 60). During this time, they skate between 2300 and 6800 m, and perform 6.8 ± 1.1 shifts per game with each shift lasting from 30 to 85 seconds followed by about two to five minutes of rest (53, 55, 60). In contrast, goaltenders usually play all three periods (3 x 20 min) with occasional overtime. Instead of two- to five-minute breaks between shifts, goaltenders get roughly 15 to 18 minutes of rest between each period and some smaller rest periods when the game shifts to the other side of the ice (34). In addition, goaltenders can receive extended rest periods between games by having another goaltender play, whereas forwards and defenders are generally expected to play each game. During a power play, one of the teams is short-handed (4 vs. 5 players) for two, four, or five minutes, depending of the type of penalty (17). As a consequence, greater physical demands are placed on the goaltender of the short-handed team who has to move laterally and vertically more often (4). Compared to forwards and defenders, goaltenders have lower VO_2max values, and reach lower post-game blood lactate (BLa) concentrations (43, 49). It has been shown that the small post-game elevation of BLa in goaltenders is usually not significant when compared to their resting level (27, 49, 78). Because goaltenders have a different role to play than defenders and forwards, they have different physical and physiological demands that may need to be trained accordingly (60, 80). They require technical and mental skills that include quickness, agility, speed, explosiveness, flexibility, fast reaction time, eye-hand coordination, and fast decision making (4).

Goaltenders from the National Hockey League (NHL) are still being evaluated by the same assessments forwards and defenders go through during NHL Combines. This might potentially lead to biased results because these tests aren't specifically designed to assess actions usually performed by goaltenders. The NHL Combine usually includes several of the following tests: the Wingate 30-second anaerobic power test, the Pro agility test (5-10-5), an aerobic capacity test, jump tests (long, counter movement, squat), and push-ups, bench press, isometric push and pull, pull-ups, sit-ups, grip strength, and flexibility test, most commonly the sit-and-reach test (11, 60).

The main objective of our study is to conduct the first systematic review and meta-analysis of the literature examining the physiology and assessment of goaltenders, and present a physiological profile of ice-hockey goaltenders based on measurements taken from NHL combine tests. Furthermore, this review will allow us to 1) highlight physiological differences between goaltenders and players at other positions, 2) determine strengths and weaknesses of ice hockey goaltenders, and 3) offer possible guidelines for strength and conditioning coaches.

METHODS

Experimental Approach to the Problem

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (42). Six electronic databases (PudMed, GoogleScholar, SportDiscus, Scopus, SpringerLink and ScienceDirect) suggested by several universities from the region of Montreal were systematically searched in October 2019. In SportDiscus and Scopus, the wildcards goal* and test* were used. In ScienceDirect and GoogleScholar, the keyword list was separated because the maximum number of words allowed was reached. In Scopus, SportDiscus, PubMed and GoogleScholar, the keywords were also translated in French. The keywords used for the search strategy can be seen in Figure 1. The search strategy was directed towards articles published from 1972 to 2019 because the excitement for ice hockey increased dramatically after the 1972 Summit Series between Canada and the USSR. This event created a keen interest in hockey science (82). Earlier articles would have been misleading because there was little to no differentiation made between the position and physiology of players, and most of the testing material was different back then. Furthermore, our review was carried out in accordance to the ethical standards of the International Journal of Exercise Science (51).

Inclusion and Exclusion Criteria

Duplicates: All duplicated articles were manually discarded by placing titles in alphabetical order using version 5.0.95.3 of Zotero. If an article was presented twice but with a different year of publication or in a different journal, it was considered different and not discarded.

Titles and Abstracts: If by reading the title or the abstract, the authors could clearly identify that the groups presented in the study were not ice hockey players, that the article was clearly about injuries and equipment, or that the article was not a scientific article published in a peer-reviewed journal, the article was discarded. Therefore, conference papers, review articles, keynotes, theses, and other types were discarded.

Text and Language Barrier: Articles were discarded if they were not written in French or English, and if their text did not present data on ice hockey goaltender physiology or physical testing at any technical level.

Data: The data from the selected articles had to present group means, and the number (*n*) of goaltenders. In addition, the data for goaltenders had to be separated according to sex and level (i.e., amateur and professional).

Contacting Authors: When clarification was needed to ensure that the retained article met all of the inclusion criteria, the corresponding author of the article was contacted twice by e-mail. If the author did not respond to both e-mails, other contributing authors whose emails were found through a Google search were contacted once. If no response was received from any of the authors contacted, the article was discarded.

Manual Search: A manual search was performed using the reference list of all articles retained from the systematic selection process.

Procedures

Values: Once all suitable data was entered, a procedure for matching test results was performed using two spreadsheets: a combination of every mean from each assessment conducted on goaltenders of the same sex and level. Thus, each test result is presented as a combined mean (X) with a combined standard deviation (SD). Combined means and SDs were normalized to their respective *n* and the total *n* by following a Weighted Mean approach (42). Professional (PM) and amateur males (AM), and amateur males and females (AM & AF) were compared with an independent samples t-test between their results (weighted mean) from each category (42). When necessary, body weight, height, combined grip strength, and vertical and long jump results were converted to kilograms (kg), centimetres (cm), kg, and cm, respectively, to facilitate comparisons. Since different methods were used to determine aerobic capacity, the authors utilised VO_2peak or VO_2max to represent maximal aerobic capacity. These two variables were previously considered as equal by Fairshter et al. (22). Therefore, the current review did the same. The anaerobic power values in Table 1 came from the 30-second Wingate cycle ergometer test (60, 78, 80). Three other articles (11, 26, 34) were not included into the analysis due to different methodologies and measures.

Verification Methods: The PRISMA model was repeated by a second author to validate included articles. Any disagreement between both reviewers over the eligibility of particular studies was resolved through discussion with a third author.

RESULTS

According to Figure 1, this systematic review presents twelve scientific research articles published in peer-reviewed journals from 1972 to 2019. The systematic search yielded a total of eight articles containing suitable results (1, 11, 26, 60, 63, 68, 71, 80), and an additional four articles were identified through the manual search (34, 70, 72, 78). The results allowed the comparison between 322 goaltenders (282 men and 40 women) with levels ranging from amateur to professional for men, and only the amateur level for women. Five articles (1, 60, 71, 72, 78), four articles (11, 34, 68, 80), and three articles (26, 63, 70) included professional male, amateur male, and amateur female goaltenders, respectively.

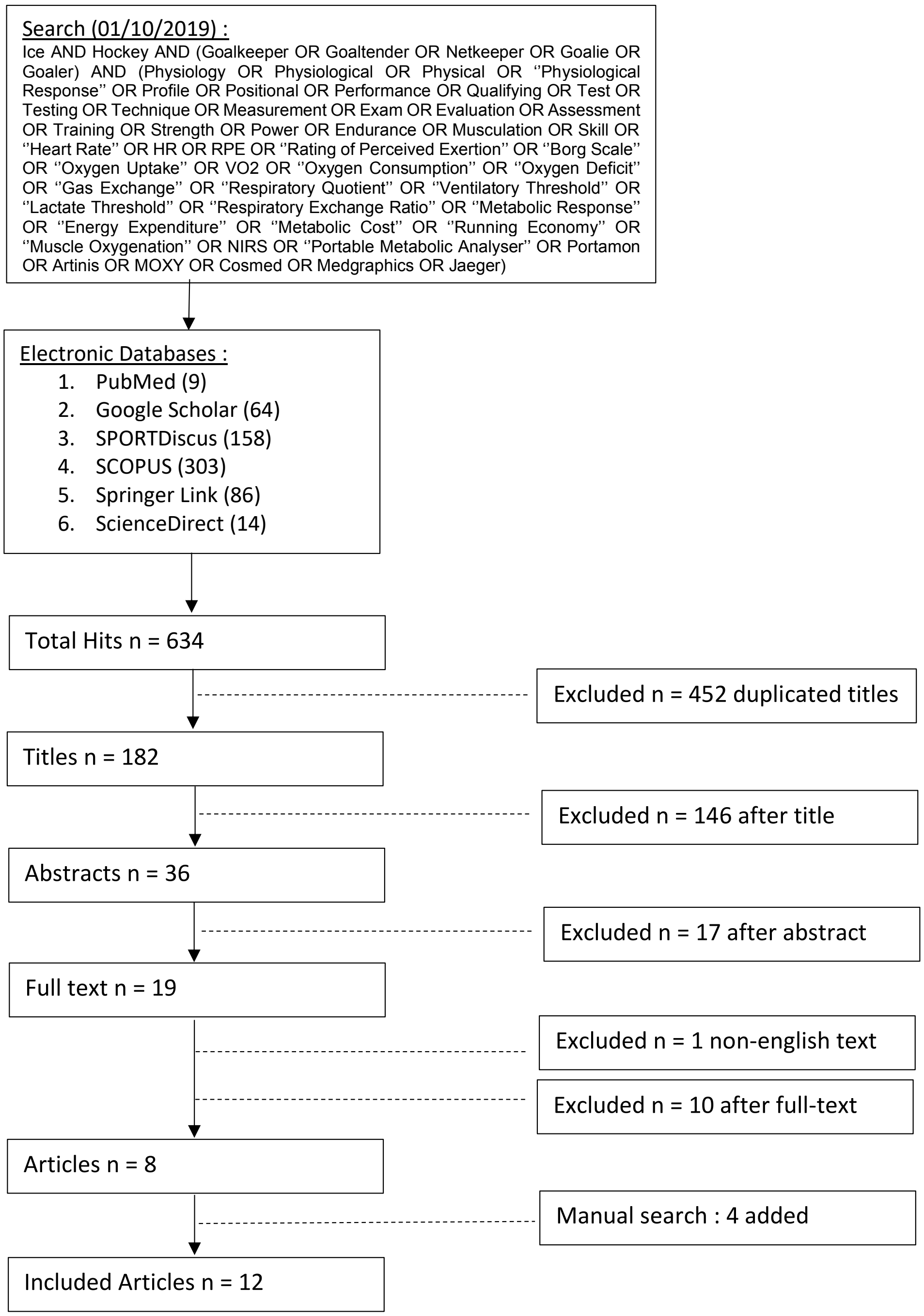

Figure 1. Flow diagram of the search strategy and articles selection process.

According to Table 1, which summarizes the anthropometry, aerobic capacity, and anaerobic power of ice hockey goaltenders, professional male (PM) goaltenders had significantly greater bodyweight and percentage body fat than amateur male (AM) goaltenders. However, the average height of PM and AM goaltenders was similar. Amateur male goaltenders were significantly heavier and taller than AF goaltenders, but AF goaltenders had a higher percent of body fat than AM, and PM goaltenders. Maximum oxygen consumption varies according to playing level and sex, and Wingate Power Peak 5s is significantly different between PM and AM goaltenders.

Table 1. Anthropometric, aerobic and anaerobic capacity profile of goaltenders.

Description			Anthropometrics				Aerobic Capacity	Anaerobic Power
Level	Sex	Data	Age (yrs)	Body weight (kg)	Height (cm)	Body fat (%)	VO_2max (ml/kg/min)	Power peak 5s (W/kg)
P	M	Mean	26.8**	85.64**	184.38	11.9**	49.9**	12.78**
		SD	2.5	3.79	2.79	2.22	4.45	1.63
		N	124	168	168	12	57	53
A	M	Mean	18.12	83.95	184.96	10.51	55.73	10.9
		SD	0.75	4.51	2.06	1.61	4.57	1.2
		N	114	113	113	114	113	24
A	F	Mean	21.04*	63.4*	164.86*	22.12*	42.84*	
		SD	1.84	5.14†	5.73†	2.27†	3.59	
		N	13	40	16	40	37	

*Significant difference between amateur (A) males (M) and females (F) at $p < 0.001$. **Significant difference between professional (P) and amateur (A) males at $p < 0.001$. †The study by Sidhu et al. (70) was not taken into consideration for this calculation because it did not include any standard deviations.

Table 2 summarizes physical fitness performance for muscular strength, endurance, and power, flexibility, and on-ice speed and agility in professional and amateur ice hockey goaltenders. According to Table 2, PM goaltenders exhibit greater isometric hand-grip strength and abdominal muscular endurance than AM goaltenders. Furthermore, AM goaltenders generate greater dynamic lower-body muscular strength and power than AF goaltenders based on their superior performance on the VJ test.

Table 2. Off-ice and on-ice physical fitness of ice hockey goaltenders.

			Muscular Strength and Endurance						Muscular Power		On-Ice SA		Flexibility
Level	Sex	Data	Bench press (reps)	Curl-ups (reps)	Push-ups (reps)	Combined hand grip (kg)	Isometric push (kg)	Isometric pull (kg)	VJ (cm)	LJ (cm)	6.1m AS (s)	CSTA (s)	SR (cm)
				60.5**		120.7**							44.8
P	M	Mean		25.16		15							8.43
		SD		53		53							57
		N	4.62	24.67	21.38	109.08	109.41	110.03	58.99	244.19			44.66
A	M	Mean	3.98	8.79	4.82	14.06	25.11	12.79	4.23	14.55			5.7
		SD	107	107	107	83	107	107	107	107			107
		N							46.88*		1.58	12.68	
A	F	Mean							5		0.07	0.42	
		SD							37		13	13	

P: Professional, **A**: Amateur, **M**: Male, **F**: Female, **VJ**: Vertical Jump, **LJ**: Long Jump, **6.1mAS**: 6.10 m acceleration sprint test, **CSTA**: Cornering S-Turn Agility, **SR**: Sit & Reach, *Significant difference between amateur (A) males (M) and females (F) at $p < 0.001$. **Significant difference between professional (P) and amateur (A) males at $p < 0.001$.

Table 3 summarizes positional differences between goaltenders, forwards, and defenders for aerobic and anaerobic performance. Professional male forwards, and defenders have been shown to exhibit a better performance on the Bruce Protocol Treadmill Test (BPTT) than goaltenders (78). The same pattern was seen on the Maximal Graded Ergometer Test (MGCET) and Wingate (WG) Test in PM and AM ice hockey players (11, 60, 78, 80). Unfortunately, Twist and Rhodes (78) did not mention whether the results for PM goaltenders on the BPTT, and the 30s-WG test were significantly lower, when compared to forwards and defenders. Positional differences were not observed in AF ice hockey players who performed the MGCET (11, 60).

Table 3. Aerobic and anaerobic performance differences between forwards, defenders and goaltenders.

		Aerobic			Anaerobic			
Authors	Level/sex	BPTT	MGCET	MSRT	WG	CF Test	MKPT	40-YD
Agre et al., 1988 (1)	PM	NS						
Twist and Rhodes, 1993 (78)	PM	F, D>G*			F, D>G*			
Quinney et al., 2008 (60)	PM		F, D>G		NS			
Houston et al., 1976 (34)	AM	NS				NS	NS	
Vescovi et al., 2006 (80)	AM		NS		F, D>G			
Burr et al., 2008 (11)	AM		F, D>G		F, D>G			
Geithner et al., 2006 (26)	AF			NS			NS	NS
Ransdell et al., 2013 (63)	AF			NS				

NS: No significant differences. * The authors did not indicate if the differences were significant, and a *p*-value was not indicated either. **F**: Forwards, **D**: Defenders, **G**: Goaltenders, **PM**: Professional Male, **AM**: Amateur Male, **AF**: Amateur Female**, BPTT**: Bruce Protocol Treadmill Test, **MGCET:** Maximal Graded Cycle Ergometer Test, **MSRT**: 20-m Multistage Shuttle Run Test, **WG**: Wingate Test on Cycle ergometer, **CF Test**: Cunningham and Faulkner Test, **MKPT**: Margaria-Kalamen Power Test, **40-YD**: 40-YD Dash.

Table 4 summarizes the positional differences for muscular endurance, isometric strength, muscular power, flexibility, and on-ice speed and agility in ice hockey players. According to Table 4, forwards demonstrated a significantly better performance in all of the parameters followed by defenders, and finally, goaltenders, except for flexibility, which showed the reverse order. Significant positional differences were found in AM players for muscular endurance based on the performance of the bench press and push-ups only (11, 80). In addition, significant positional differences were observed in AM and PM players for isometric muscular strength based on combined hand grip, and isometric P&P test results (11, 60). Only one study (11) showed significant positional differences for muscular power using vertical and long jumps. Flexibility, measured using the sit-and- reach test, was significantly greater for PM and AM goaltenders compared to defenders and forwards (11, 60, 80). Finally, only one study examined positional differences using on-ice tests, and the subjects of the study were AF players (26). According to this study, significant differences were observed between positions for the CSTA test, but not the 6.1mAS test.

Table 4. Strength, power and flexibility performance differences between forwards, defenders, and goaltenders.

		Muscular Endurance and Isometric Strength							Muscular Power		On-Ice Testing		Flexibility
Authors	Level Sex	Curl-ups	Bench press	Push-ups	Pull-ups	Inverted rows	Isometric P&P	Combined hand grip	VJ	LJ	6.1mAS	CSTA	SR
Agre et al.,1988 (1)	PM												F, D<G*
Quinney et al., 2008 (60)	PM	NS						F, D>G					F, D<G
Vescovi et al., 2006 (80)	AM	NS	F, D>G	F, D>G			F, D>G		NS	NS			F, D<G
Burr et al., 2008 (11)	AM	NS	F, D>G	F, D>G			F, D>G	F, D>G	F, D>G	F, D>G			F, D<G
Geithner et al., 2006 (26)	AF								NS		NS	F, D<G	
Ransdell et al., 2013 (63)	AF				NS	NS			NS	NS			

*The authors did not indicate if the differences were significant, and a p-value was not indicated either. **NS**: No significant differences, **F**: Forwards, **D**: Defenders, **G**: Goaltenders, **PM**: Professional Male, **AM**: Amateur Male, **AF**: Amateur Female, **Isometric P&P**: Push & Pull, **VJ**: Vertical Jump, **LJ**: Long Jump, **6.1mAS**: 6.10m Acceleration Sprint, **CSTA**: Cornering S-Turn Agility Test, **SR**: Sit & Reach

DISCUSSION

The current systematic review aimed to analyze, from a quantitative and qualitative point of view, the findings provided in the scientific literature regarding the physiological profile of ice hockey goaltenders, the physical assessments utilised to evaluate them, and compare their performance differences to forwards and defenders. One of the main findings of our review is that a fair number of published articles excluded the goaltenders or did not specify players' position in their methods. Furthermore, only one article (26) performed an on-ice assessment that included goaltenders (81). This is surprising because it is clearly known that an on-ice assessment is more specific for ice hockey players (41, 56). Nonetheless, this review allowed us to gather the results from all articles published on the physiology and physical testing of ice hockey goaltenders and compare them to players at different positions.

The physical fitness of a professional goaltender has changed over the years. It has been influenced by secular trends, rule changes, and sports selection through years (4, 50, 71, 72). For example, several NHL rule changes improved the flow of the game, increased offensive play, and reduced the goaltender's ability to play the puck in certain areas of the ice surface. In fact, in the 2003-2004 season, teams averaged 348 powerplays while this number increased to 480 in 2005-2006 (4). As a consequence, an increase in the number of powerplays increased the activity of goaltenders requiring them to develop a higher physical fitness level than in previous years. Therefore, a goaltender must be more physically fit to endure such physical activity demands.

Description: Normally, PM goaltenders are significantly older than amateurs, which can be explained by the fact that biological maturity is a predictor utilised during hockey camp selections to determine which players will access higher playing levels (69). The age differences seen between AM goaltenders and AF goaltenders can be explained by the differences in hockey categories between men and women, as women stay longer at the amateur level because they are offered fewer opportunities to participate at the elite level (83).

Anthropometry: No significant differences were found for height between PM and AM goaltenders. According to a study by Sigmund et al. (71), it has been observed that the height of professional goaltenders has increased recently. This increased height allows them to cover a larger area of the goal. Before the NHL made several rule changes in 2005-06, defenders were the tallest and heaviest players followed by forwards, and finally goaltenders (1, 60, 80). Recently, goaltenders are the tallest when compared to their teammates with an average height of 188.98 cm (39, 72). However, a recent study by Vigh-Laresen et al. that came out in 2020 (after our original search) did not find any differences in height between Finnish and Danish professional forwards, defenders and goaltenders (81). Goaltender's height was also similar to what is shown in the current literature with 189.1 ± 5.2 cm for Finnish goalies and 185.2 ± 7. 8 cm for Danish ones (81). Professional male hockey goaltenders are significantly heavier than AM goaltenders, which can be explained by the greater amount of time PM goaltenders spend on strength and aerobic exercise training (33, 62). According to the current scientific literature, weight differences exist between forwards, defenders, and goaltenders. Most studies have shown that goaltenders are just as heavy as forwards, and lighter than defenders (1, 16, 60, 71, 72, 78). However, a study by Vigh- Larsen et al. (81) reported no difference between positions in Finnish (F: 86.1 ± 8.4 kg, D: 86.2 ± 6.8 kg, G: 86.5 ± 6.9 kg) and Danish (F: 84.1 ± 7.8 kg, D: 84.5 ± 9.0 kg, G: 82.6 ± 6.1 kg) hockey players. As well, no matter the playing level or sex, the higher BF% observed in goaltenders may be explained by the lower cardiovascular demands of this player position (1, 11, 34, 60, 70, 75, 76, 78, 80). Stanzione, Dardarian and colleagues (75) also observed higher BF% in goaltenders (19.2 ± 4.4 %) when compared to forwards (15.3 ± 2.3%) and defenders (14.4 ± 2.6%) (75). BF% has been linked to skating performance. When skating on ice, a higher body mass increases the frictional resistance a player must overcome which requires a greater amount of energy to skate at a specific velocity (28). Since goaltender do not need to skate great distances, like defenders and forwards, the effects on their additional fat-mass on skating velocity should not be considered an issue of concern (16, 28, 59). However, the additional body fat in goaltenders can act as a protective barrier against physical contact and subsequent injury (16).

Aerobic Capacity: Aerobic metabolism is required for goaltenders to recover between short and high intensity periods, maintain an alert and ready position for long periods of time, and make numerous saves during short intense durations (36). It is somehow surprising that AM goaltenders have a significantly higher VO_2max than professionals (Tables 1 and 3). This difference may be explained by the fact that PM goaltenders spend more time scrimmaging, practicing, developing tactics and strategies, while allotting less time to aerobic training than AM goaltenders. As well, previous studies observed that AF (25), AM (36, 49), and PM (49, 78) goaltenders experience none or only a small elevation in BLa when compared to their resting levels. It shows that goaltenders have sufficient time to resynthesize ATP and PCr to recover between their fast and explosive actions (36, 64, 78). In fact, according to a study conducted by Richard et al. (64), low-, moderate, and high-intensity actions represented 75.2%, 21.6%, and 3.2% of game time, respectively, in young, non-elite goaltenders. Additionally, Montgomery (48, 49) showed the mean heart rate (HR_{mean}) of nine recreational goaltenders was 143 beats per minutes (bpm), which is approximately 64% of their maximal heart rate (HR_{max}). Throughout a hockey game, a goaltender's playing intensity is usually at a level that requires the greatest contribution from aerobic metabolism (36).

In the current literature, comparisons between on-ice and off-ice maximal aerobic capacity assessments in goaltenders are lacking. As a result, the literature is mostly comprised of off-ice testing. On-ice testing would provide more accurate assessments of VO_2max and lactate threshold because it requires a higher muscle mass activation than running or cycling, and it matches the demands of ice hockey more closely (35, 52). Out of the eight articles that made an off-ice assessment of VO_2max, five concluded that there are no significant differences between forwards, defenders, and goaltenders (1, 26, 34, 63, 80). The results of this review show that goaltenders have similar maximum aerobic capacities to defenders and forwards when VO_2max is assessed by running (Table 3). A potential explanation for this similarity is that the biomechanics of running are closer to skating than cycling because skating relies more on impulse than the stretch-shortening cycle (52). Also, vertical, and lateral movements are frequently performed by goaltenders and can be replicated more easily through running rather than cycling (4, 35). Thus, running is a more viable option than cycling if on-ice testing is not possible. Finally, the variety of tests used to assess off-ice aerobic capacity may have influenced the results of the relation between off-ice and on-ice VO_2max in the literature (55, 57).

Anaerobic Power and Capacity: Anaerobic power and capacity are two factors that are well known to be of critical importance in hockey performance (49). The goaltender's actions are characterized by fast, repetitive, and explosive movements of short duration with periods of lower intensity actions or rest (78). Professional male goaltenders produce significantly more relative peak power than AM goaltenders when performing the 30-s Wingate (WG) test (Table 1). Previous research has shown that American college Division I players exhibit a higher anaerobic capacity than lower Division III players (55). Furthermore, anaerobic capacity is a significant predictor for team selection (66).

In forwards and defenders, it has been clearly shown that the 30-s WG test is the most commonly used test to assess anaerobic power and capacity due to its correlation with on-ice sprint performance (15, 21, 49, 65). Nevertheless, to the best of our knowledge, no study has been done on goaltenders to compare off-ice and on-ice anaerobic testing. According to Table 3, the performance of professional and amateur male goaltenders during the execution of the 30-s WG test is lower compared to their teammates at other playing positions (11, 78, 80). Mascaro et al. suggested that the inferior performance of goaltenders on the 30-s WG test may be explained by the fact they do not receive any training dedicated to increase speed performance as is customary in forwards and defenders (45). In contrast, a study by Cox et al., using a 45-s protocol rather than the common 30-s approach for the WG test, found no significant performance differences between goaltenders and players at other positions (15). This result can be explained by the fact that a 45-s WG test engages a lower intensity (% VO_2peak), and a greater recruitment of aerobic metabolism than the 30-s WG test, which is closer to the positional demands of a goaltender (13).

According to Table 3, running does not show differences between player positions for anaerobic capacity assessments, while cycling elicits a significantly weaker result in goaltenders. Running mechanics may be more similar to the pushing action performed by goaltenders on ice than cycling. Hockey players who can run fast will also be able to skate fast and maintain a high work output during their ice time (7). The 40-YD dash has been shown to be a strong predictor of skating speed in women's ice hockey players (7). The results of the 40-yd dash can be used to predict anaerobic capacity with the formula developed by Watson and Sargeant (7, 37). Finally, the 40-YD dash could be a good option for off-ice assessment if on-ice assessment is not possible because the results of this test are considered good predictors of skating performance (7).

Muscular Strength and Endurance: The current scientific literature shows that goaltenders present lower dynamic and isometric strength results than their teammate's (11, 60, 78, 80). Total upper body strength assessments performed by Vescovi et al. and Burr et al. show that goaltenders have lower strength and endurance than forwards and defenders (11, 80). This difference should not be considered a weakness for goaltenders because upper body strength is not primordial to perform their role adequately (80). On the other hand, because of their vulnerable position, upper body strength is required to protect them against contacts and hold their stick (36). Only one study presented results on upper body strength with AF; Ransdell et al. (63) evaluated female players on pull-ups or inverted row tests if the players weren't able to perform a full pull up. There was no significant difference between AF forwards, defenders, and goaltenders.

According to a study by Quinney et al. (60), successful NHL teams have a greater combined grip strength than unsuccessful ones, which suggests that isometric grip strength is important for hockey performance. Table 2 indicates that the combined isometric hand grip strength of PM goaltenders is significantly greater than in AM goaltenders (60, 78). However, our results show that goaltenders have a lower grip strength than their teammates, which is surprising because they must resist the rotational forces of wrist shots reaching speeds up to 50-70 mph, and 70-to-90-mph slap shots with their goalie stick (3, 8). In addition, goaltenders require an adequate grip strength to control and maneuver their stick (8). Regardless, it appears that grip strength is a more important factor for forwards and defenders to perform wrist shots and slap shots than it is for goaltenders to resist the rotational forces of such powerful shots (29, 40). Although the bench press, push-up, isometric push-and-pull tests are usually performed during the NHLED Combine, there is little data from these assessments in goaltenders (52).

A goaltender's stance involves unique physical and biomechanical demands, such as: 1) a high recruitment of hip adductor, flexor, and rotator muscles which are crucial in lateral movement push-offs, 2) strong lower limbs to repeat dropping down into the butterfly position, 3) good core muscular endurance and strength which are needed during abrupt changes in direction to make saves, and to pass and clear the puck with their stick (36, 46). For instance, Table 2 demonstrates that PM goaltenders have a significantly greater abdominal endurance than AM goaltenders. Our review suggests that core muscular endurance is more important in PM goaltenders. At the national level, male goaltenders are required to complete a minimum of 35 repetitions of the curl-up, which is more than what amateurs were able to perform in Quinney et al.'s study (61). As indicated in Table 4, significant differences do not exist between any position for male players at the professional and amateur levels when abdominal muscular endurance is assessed using curl-ups (11, 60, 80). Abdominal endurance is fundamental for all players, no matter what position they play, because it allows for good stability to perform fast velocity actions (60). It has been shown that a strong core stability improves the muscular power and movement speed of the peripheral limbs, as well as the muscular strength of the lower limbs (12). Also, a strong core stability allows goaltenders to keep good balance and protect them against contact (46). A high level of abdominal endurance may reduce the risk of injury and lower back pain (2, 60, 61). Therefore, abdominal stability assessment is a pertinent tool to use with goaltenders as abdominal stability can impact velocity of vertical movement (12).

Muscular Power: In the NHLED Combine, the VJ and LJ are used to measure lower limb power (11, 52, 79). Surprisingly, studies examining muscular power in professional male goaltenders using the VJ and LJ were not found in the current literature. However, in 2020, Vigh-Larsen et al. (81) showed no significant performance differences between position for Danish and Finnish elite players for the countermovement VJ (81). The VJ has been found to be a very consistent predictor for both acceleration and speed in male and female ice hockey players (7, 23, 30, 35, 37, 45, 67). Furthermore, the VJ has been shown to be highly correlated with knee extension power at 180 degrees (45), which is a biomechanical action frequently used by goaltenders (4, 36). Two of the greatest qualities of a goaltender include a fast reaction time, and moving quickly (4). Likewise, neuromuscular testing is recognized as one of the most important parameters to test for in these players (4, 36, 73, 78, 80). Excluding the study by Burr et al. (11), most studies did not find any statistical differences between positions for the VJ (26, 63, 80) and LJ (63, 80) at the amateur level, whether it was performed by men or women (Table 4). The same absence of differences was seen in Vigh-Larensen et al.'s study on elite Finnish and Danish players (81). There are several explanations for these results. First, the VJ requires activation of the same muscle groups as one of the most frequent actions performed by goaltenders, which is dropping down into the butterfly position from the ready position, and rising up from one or both leg pads (4, 36). Second, as opposed to the VJ, the LJ is associated with a greater recruitment of the core (54) and upper body muscles (14), which is similar to the muscular recruitment during the propulsion of a front-to back on-ice action (4, 36). To further support this explanation, Meylan et al. (47) also found that these types of jumps measured different leg power qualities and should not be used interchangeably. Third, the absence of differences between position may reflect that lower body power is equally important to ice hockey players no matter what position they play, as it allows them to generate powerful muscle contractions in a short period of time (6).

Flexibility: Flexibility and mobility are important components of physical fitness for goaltenders and should not be overlooked. Goaltenders need to execute movements in all three planes of motion at the hip joint which enable them to react properly to sudden changes of play, make saves and reduce the risk of injury (4, 36, 44, 46). In fact, maximal hip internal rotation is seen 32.6% of the time during skating, and 21.2% while maintaining the butterfly position (77), a position that requires significant levels of hip motion to properly recover from saves and decelerate during skating (19, 30). Sustaining this position for long periods can be a precursor to symptomatic femoro-acetabular impingement (FAI), seen commonly in goaltenders (38, 58, 77). To avoid such an injury, particular attention should be paid to monitoring young goalies for FAI by watching out for progressive hip internal rotation. The absence of significant differences between league level can potentially be explained by the fact that goaltenders need good hip mobility and flexibility to perform their role independently of their playing level. This factor does not change the movements they are expected to perform during an ice hockey game.

The CSTA and 6.10-mAS tests are common on-ice tests used to assess skating agility, and speed, respectively, in ice-hockey players (6, 25, 26, 32). According to our systematic review, most studies used these two on-ice tests to assess hockey players, but they did not specify test results for goaltenders (6 ,25, 32). However, one study by Geithner et al. (26) used these same two on-ice tests to assess goaltenders, defenders, and forwards. In their study, the performance of goaltenders on the CSTA test was lower compared to defenders and forwards. In contrast, the goaltenders' performance on the 6.10-mAS test did not exhibit a significant difference compared to the performance by defenders and forwards. These results can be explained by the fact that the CSTA accurately represents the game skating biomechanics of forwards and defenders, but not the goaltender's actions (6).

A recent study with 17 years of data on the relative VO_2max from professional ice-hockey players measured during the pre-season training camps of an NHL organization showed no significant differences in relative VO_2max between generations, level of play, and playing position, other than with the East Coast Hockey League (ECHL). It also showed no relationship between VO_2max values and NHL career statistics (24). This study assessed players with the Skating Multistage Aerobic Test (SMAT) and the 30-15 Intermittent Ice Test (30-15 IIT). Finally, our review did not find any studies that performed on-ice assessments specifically designed for goaltenders. This area deserves further attention from sports scientists.

PRACTICAL APPLICATIONS

By understanding the relationship between the variables examined in our systematic review, it may be possible to establish a range of physiological responses that are desirable to determine the physical performance of ice hockey goaltenders. The results from Tables 1 and 2 could serve as benchmark values for strength and conditioning specialists when they work with goaltenders of different levels. The current review shows that aerobic and anaerobic tests are performed, but it is still unclear which tests are the most pertinent to assess goaltender performance. The 30-15 IIT, the 5-10-5 Pro-Agility test, and the Maximal Yo-Yo Intermittent Recovery Level 1 Ice Hockey Test would be interesting to assess the aerobic capacity of goaltenders due to the intermittent nature of hockey (24, 81). Therefore, strength and conditioning coaches (SCC) should focus on testing core and grip strength, lower limb power, and flexibility with goaltenders. Finally, it is clear that goaltenders require specific training and testing adapted to their particular position.

LIMITS

In general, our review had several limitations. First of all, some studies had a small number of participants which potentially affected the precision of their results. Second, some studies differed in the homogeneity of their participants (i.e., age and playing level), and in the implementation of their interventions. Third, the equipment and tests used to assess specific components of physical fitness were not the same in all studies. Thus, based on these factors, we must assume that effect sizes varied in the different studies.

CONCLUSION

The goal of this review was to present all original scientific investigations published about the physiology and testing of ice hockey goaltenders. A goaltender's height will influence the area of the goal that can be covered. Therefore, taller players are prioritized during team selection. Aerobic testing of goaltenders is important because most of their actions rely mainly on contribution from aerobic metabolism, but anaerobic power is also essential to execute rapid and explosive movements to save the puck. Strength qualities should emphasize core muscle and hand grip strength. Finally, having mobile hips and good overall flexibility of the hamstrings are crucial to goaltender performance. This profile is only partial as there is a limited amount of data for goaltenders in the current literature. This limitation may be explained by the fact that researchers need to recruit goaltenders form many teams to achieve an acceptable sample size to carry out valid and reliable on-ice assessments. The literature appears to show that not much thought has been placed in the testing of goaltenders. Nevertheless, these results should be interpreted carefully as several different assessments were used to measure the same parameter. Meanwhile, this review presents positional differences, and provides a profile of amateur and professional ice hockey players. We found several deficiencies in the current literature, such as a low number of studies on female players, a lack of distinction between player position in the results section of studies, and a lack of precision in the methods and protocols used in some studies. Athletes, regardless of their sport, should be trained in a holistic manner. Testing is important because it can uncover strengths and weaknesses of an athlete. Therefore, SCC should focus on the muscular strength, power, and endurance of goaltenders. Although goaltenders seem to possess a greater amount of strength in the lower body muscles, SCC should take time to improve their upper body strength to protect them against contact injuries. Based on SCC and goaltender telephone interviews (November 6, 2019; six goaltender SCC and three goaltenders), goaltenders require some form of measurement for mental fortitude, ability to concentrate, visual acuity, reflex speed, and balance. Thus, based on the results presented herein, specific assessments should be created for goaltenders, as their position/role requirements are very different from their teammates.

REFERENCES

1. Agre JC, Casal DC, Leon AS, McNally C, Baxter TL, Serfass RC. Professional ice hockey players: physiologic, anthropometric, and musculoskeletal characteristics. Arch Phys Med Rehabil 69(3 Pt 1): 188–192, 1988.

2. Albert WJ, Bonneau J, Stevenson JM, Gledhill N. Back fitness and back health assessment considerations for the canadian physical activity, fitness and lifestyle appraisal. Can J Appl Physiol 26(3): 291–317, 2001.

3. Alexander JF, Haddow JB, Schultz GA. Comparison of the ice hockey wrist and slap shots for speed and accuracy. Res Q Am Assoc Health Phys Educ Recr 34(3): 259–266, 1963.

4. Bell GJ, Snydmiller GD, Game AB. An investigation of the type and frequency of movement patterns of National Hockey League goaltenders. Int J Sports Physiol Perform 3(1): 80–87, 2008.

5. Besson C, Buchheit M, Praz M, Dériaz O, Millet GP. Cardiorespiratory responses to the 30-15 intermittent ice test. Int J Sports Physiol Perform 8(2): 173–180, 2013.

6. Bracko MR, Fellingham GW. Comparison of physical performance characteristics of female and male ice hockey players. Pediatr Exerc Sci 13: 26–34, 2001.

7. Bracko MR, George JD. Prediction of ice skating performance with off- ice testing in women's ice hockey players. J Strength Cond Res 15(1): 116–122, 2001.

8. Brenner C. Hockey Goalie Stick (U.S Patent No. US 9,101,804 B2). Lanesborough, MA. U.S. Patent and Trademark Office; 2015.

9. Brocherie F, Babault N, Cometti G, Maffiuletti N, Chatard J-C. Electrostimulation training effects on the physical performance of ice hockey players. Med Sci Sports Exerc 37(3): 455–460, 2005.

10. Buchheit M, Lefebvre B, Laursen PB, Ahmaidi S. Reliability, usefulness, and validity of the 30-15 intermittent ice test in young elite ice hockey players. J Strength Cond Res 25(5): 1457–1464, 2011.

11. Burr JF, Jamnik RK, Baker J, Macpherson A, Gledhill N, McGuire EJ. Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. J Strength Cond Res 22(5): 1535–1543, 2008.

12. Butcher SJ, Craven BR, Chilibeck PD, Spink KS, Grona SL, Sprigings EJ. The effect of trunk stability training on vertical takeoff velocity. J Orthop Sports Phys Ther 37(5): 223–231, 2007.

13. Calbet JA, Chavarren J, Dorado C. Fractional use of anaerobic capacity during a 30- and a 45-s Wingate test. Eur J Appl Physiol 76(4): 308–313, 1997.

14. Castro-Piñero J, Ortega FB, Artero EG, Girela-Rejón MJ, Mora J, Sjöström M, et al. Assessing muscular strength in youth: usefulness of standing long jump as a general index of muscular fitness. J Strength Cond Res 24(7): 1810–1817, 2010.

15. Cox MH, Miles DS, Verde TJ, Rhodes EC. Applied physiology of ice hockey. Sports Med 19(3): 184–201, 1995.

16. Delisle-Houde P, Reid RER, Insogna JA, Prokop NW, Buchan TA, Fontaine SL, Andersen RE. Comparing DXA and air displacement plethysmography to assess body composition of male collegiate hockey players. J Strength Cond Res 33(2): 474–478, 2019.

17. Douglas AS, Kennedy CR. Tracking in-match movement demands using local positioning system in world-class men's ice hockey. J Strength Cond Res 34(3): 639–646, 2020.

18. Dreger RW, Quinney HA. Development of a hockey-specific, skate-treadmill VO_2max protocol. Can J Appl Physiol 24(6): 559–569, 1999.

19. Durocher JJ, Guisfredi AJ, Leetun DT, Carter JR. Comparison of on-ice and off-ice graded exercise testing in collegiate hockey players. Appl Physiol Nutr Metab 35(1): 35–39, 2010.

20. Durocher JJ, Leetun DT, Carter JR. Sport-specific assessment of lactate threshold and aerobic capacity throughout a collegiate hockey season. Appl Physiol Nutr Metab 33(6): 1165–1171, 2008.

21. Ebben WP, Carroll RM, Simenz CJ. Strength and conditioning pratices of national hockey league strength and conditioning coaches. J Strength Cond Res 18(4): 889–897, 2004.

22. Fairshter RD, Walters J, Salness K, Fox M, Minh V-D, Wilson AF. A comparison of incremental exercise tests during cycle and treadmill ergometry. Med Sci Sports Exerc 15(6): 549–554, 1983.

23. Farlinger CM, Kruisselbrink LD, Fowles JR. Relationships to skating performance in competitive hockey players. J Strength Cond Res 21(3): 915–922, 2007.

24. Ferland PM, Marcotte-L'Heureux V, Roy P, Carey VD, Charron J, Lagrange S, Leone M, Comtois AS. Maximal oxygen consumption requirements in professional North American ice hockey. J Strength Cond Res 35(6): 1586-1592, 2021.

25. Geithner CA. Predicting performance in women's ice hockey. In: Advances in Strength and Conditioning Research. New York, NY: Nova Science Publishers; 2009.

26. Geithner CA, Lee AM, Bracko MR. Physical and performance differences among forwards, defensemen, and goalies in elite women's ice hockey. J Strength Cond Res 20(3): 500–505, 2006.

27. Green H, Bishop P, Houston M, McKillop R, Norman R, Stothart P. Time-motion and physiological assessments of ice hockey performance. J Appl Physiol 40(2): 159–163, 1976.

28. Green MR, Pivarnik JM, Carrier DP, Womack CJ. Relationship between physiological profiles and on-ice performance of a national collegiate athletic association division I hockey team. J Strength Cond Res 20(1): 43–46, 2006.

29. Haché A. The physics of hockey. Baltimore, MD: Johns Hopkins University Press; 2002.

30. Haukali E, Tjelta LI. Correlation between "off-ice" variables and skating performance among young male ice hockey players. Int J Appl Sports Sci 27(1): 26–32, 2015.

31. Heller J, Vodicka P, Janek M. Anaerobic performance in 30s Wingate test as one of the possible criteria for selection Czech hockey players into National Hockey League. Phys Act Rev 7: 57–62, 2019.

32. Henriksson T, Vescovi JD, Fjellman-Wiklund A, Gilenstam K. Laboratory- and field-based testing as predictors of skating performance in competitive-level female ice hockey. Open Access J Sports Med 7: 81–88, 2016.

33. Hoff J, Kemi OJ, Helgerud J. Strength and endurance differences between elite and junior elite ice hockey players. The importance of allometric scaling. Int J Sports Med 26(7): 537–541, 2005.

34. Houston ME, Green HJ. Physiological and anthropometric characteristics of elite Canadian ice hockey players. J Sports Med Phys Fit 16(2): 123–128, 1976.

35. Janot JM, Beltz NM, Dalleck LD. Multiple off-ice performance variables predict on-ice skating performance in male and female Division III ice hockey players. J Sports Sci Med 14(3): 522–529, 2015.

36. Kilpivaara P, Häkkinen K. Ice hockey goaltending: physiological loading and game analysis. Master's thesis in Science of Sport Coaching and Fitness Testing. Department of Biology and Physical Activity, University of Jyväskylä; 2012.

37. Krause DA, Smith AM, Holmes LC, Klebe CR, Lee JB, Lundquist KM, et al. Relationship of off-ice and on-ice performance measures in high school male hockey players. J Strength Cond Res 26(5): 1423–1430, 2012.

38. Kuhn AW, Noonan BC, Kelly BT, Larson CM, Bedi A. The hip in ice hockey: A current concepts review. Arthroscopy 32(9): 1928–1938, 2016.

39. Kutáč P, Kopecký M. Comparison of body fat using various bioelectrical impedance analyzers in university students. Acta Gymnica 45(4): 177–186, 2015.

40. Laliberte DJ. Biomechanics of ice hockey slap shots: Which stick is best? Sport J Retrieved from: https://thesportjournal.org/article/biomechanics-of-ice-hockey-slap-shots-which-stick-is-best/; 2009.

41. Leone M, Léger L, Larivière G, Comtois AS. An on-ice aerobic maximal multistage shuttle skate test for elite adolescent hockey players. Int J Sports Med 28(10): 823–828, 2007.

42. Liberati A, Altman D G, Tetzlaff J, Mulrow C, Gøtzsche PC, Loannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. J Clin Epidemiol 62(10): e1-34, 2009.

43. Lignell E, Fransson D, Krustrup P, Mohr M. Analysis of high-intensity skating in top-class ice hockey match-play in relation to training status and muscle damage. J Strength Cond Res 32(5): 1303–1310, 2018.

44. MacIntyre K, Gomes B, MacKenzie S, D'Angelo K. Conservative management of an elite ice hockey goaltender with femoroacetabular impingement (FAI): a case report. J Can Chiropr Assoc 59(4): 398–409, 2015.

45. Mascaro T, Seaver BL, Swanson L. Prediction of skating speed with off-ice testing in professional hockey players. J Orthop Sports Phys Ther 15(2): 92–98, 1992.

46. Mehta N, Nwachukwu BU, Kelly BT. Hip injuries in ice hockey goaltenders. Oper Tech Sports Med 27(3): 132–137, 2019.

47. Meylan C, McMaster T, Cronin J, Mohammad N, Rogers C, DeKlerk M. Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. J Strength Cond Res 23(4): 1140–1147, 2009.

48. Montgomery DL. Characteristics of "old timer" hockey play. Can J Appl Sci 4(1): 39–42, 1979.

49. Montgomery DL. Physiology of Ice Hockey. Sports Med 5(2): 99–126, 1988.

50. Montgomery DL. Physiological profile of professional hockey players-a longitudinal comparison. Appl Physiol Nutr Metab 31(3): 181–185, 2006.

51. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in Exercise Science. Int J Exerc Sci 12(1): 1–8, 2019.

52. Nightingale SC, Miller S, Turner A. The usefulness and reliability of fitness testing protocols for ice hockey players: A literature review. J Strength Cond Res 27(6): 1742–1748, 2013.

53. Noonan BC. Intragame blood-lactate values during ice hockey and their relationships to commonly used hockey testing protocols. J Strength Cond Res 24(9): 2290–2295, 2010.

54. Okubo Y, Kaneoka K, Shiina I, Tatsumura M, Miyakawa S. Abdominal muscle activity during a standing long jump. J Orthop Sports Phys Ther 43(8): 577–582, 2013.

55. Peterson BJ, Fitzgerald JS, Dietz CC, Ziegler KS, Ingraham SJ, Baker SE, et al. Division I hockey players generate more power than Division III players during on- and off-ice performance tests. J Strength Cond Res 29(5): 1191–1196, 2015.

56. Petrella NJ, Montelpare WJ, Nystrom M, Plyley M, Faught BE. Validation of the fast skating protocol to predict aerobic power in ice hockey players. Appl Physiol Nutr Metab 32(4): 693–700, 2007.

57. Peyer KL, Pivarnik JM, Eisenmann JC, Vorkapich M. Physiological characteristics of National Collegiate Athletic Association Division I ice hockey players and their relation to game performance. J Strength Cond Res 25(5): 1183–1192, 2011.

58. Pierce CM, Laprade RF, Wahoff M, O'Brien L, Philippon MJ. Ice hockey goaltender rehabilitation, including on-ice progression, after arthroscopic hip surgery for femoroacetabular impingement. J Orthop Sports Phys Ther 43(3): 129–141, 2013.

59. Potteiger JA, Smith DL, Maier ML, Foster TS. Relationship between body composition, leg strength, anaerobic power, and on-ice skating performance in division I men's hockey athletes. J Strength Cond Res 24(7): 1755–1762, 2010.

60. Quinney HA, Dewart R, Game A, Snydmiller G, Warburton D, Bell G. A 26 year physiological description of a National Hockey League team. Appl Physiol Nutr Metab 33(4): 753–760, 2008.

61. Quinney HA, Smith DJ, Wenger HA. A field test for the assessment of abdominal muscular endurance in professional ice hockey players. J Orthop Sports Phys Ther 6(1): 30–33, 1984.

62. Ransdell LB, Murray T. A physical profile of elite female ice hockey players from the USA. J Strength Cond Res 25(9): 2358–2363, 2011.

63. Ransdell LB, Murray TM, Gao Y. Off-ice fitness of elite female ice hockey players by team success, age, and player position. J Strength Cond Res 27(4): 875–884, 2013.

64. Richard J, Gionet N, Nowlan J. Time-motion analysis of ice hockey goaltending. J Hum Mov Stud 29(3): S115–S131, 1995.

65. Roczniok R, Adam M, Przemysław P, Stanula A, Gołaś A. On-ice special tests in relation to various indexes of aerobic and anaerobic capacity in Polish league ice hockey players. Procedia Soc Behav Sci 117: 475–481, 2014.

66. Roczniok R, Maszczyk A, Stanula A, Czuba M, Pietraszewski P, Kantyka J, et al. Physiological and physical profiles and on-ice performance approach to predict talent in male youth ice hockey players during draft to hockey team. Isokinet Exerc Sci 21(2): 121–127, 2013.

67. Runner AR, Lehnhard RA, Butterfield SA, Tu S, O'Neill T. Predictors of speed using off-ice measures of college hockey players. J Strength Cond Res 30(6): 1626–1632, 2016.

68. Seliger V, Kostka V, Grušová D, Kováč J, Machovcová J, Pauer M, et al. Energy expenditure and physical fitness of ice-hockey players. Int Z Angew Physiol 30(4): 283–291, 1972.

69. Sherar LB, Bruner MW, Munkoe-Chandler KJ, Baxter-Jones AD. Relative age and fast tracking of elite major junior ice hockey players. Percept Mot Skills 104(3 Pt 1): 702–706, 2007.

70. Sidhu LS, Grewal R, Verma SK. Positional differences in physique and body composition among top level Indian women hockey players. J Sports Med Phys Fitness 24(4): 337–342, 1984.

71. Sigmund M, Kohn S, Sigmundová D. Assessment of basic physical parameters of current Canadian-American National Hockey League (NHL) ice hockey players. Acta Gymnica 46(1): 30–36, 2016.

72. Sigmund M, Sigmundova D, Kvintova J. Basic physical profile of current Czech elite male ice hockey players. Life Sci J 12(2): 9–13, 2015.

73. Sinclair G, Moyls PW. Speed of response characteristics of goalkeepers: a descriptive and developmental report. Can J Appl Sci 4(4): 60–65, 1979.

74. Šiška M, Kováčiková Z. Effect of the off-season training on the physical profile in U18 elite male ice hockey players. J Phys Educ Sport 17(3): 1120–1124, 2017.

75. Stanzione JR, Dardarian N, Volpe SL. Body composition changes after one year in professional male ice hockey players. Int J Sports Med 41(14): 1056–1060, 2020.

76. Szmatlan-Gabryś U, Stanula A, Tomasz G, Ozimek M. Segmental body composition in male and female ice-hockey players. Life Sci J 11(5): 389–395, 2014.

77. Tramer JS, Deneweth JM, Whiteside D, Ross JR, Bedi A, Goulet GC. On-ice functional assessment of an elite ice hockey goaltender after treatment for femoroacetabular impingement. Sports Health 7(6): 542–547, 2015.

78. Twist P, Rhodes T. A physiological analysis of ice hockey positions. Strength Cond J 15(6): 44–46, 1993.

79. Vescovi JD, Murray TM, Fiala KA, VanHeest JL. Off-ice performance and draft status of elite ice hockey players. Int J Sports Physiol Perform 1(3): 207–221, 2006.

80. Vescovi JD, Murray TM, Vanheest JL. Positional performance profiling of elite ice hockey players. Int J Sports Physiol Perform 1(2): 84–94, 2006.

81. Vigh-Larsen JF, Haverinen MT, Panduro J, Ermidis G, Andersen TB, Overgaard K, et al. On-ice and off-ice fitness profiles of elite and U20 male ice hockey players of two different national standards. J Strength Cond Res 34(12): 3369–3376, 2020.

82. Watson SD. Everyday nationalism and international hockey: contesting Canadian national identity: Everyday nationalism and international hockey. Nations Nationalism 23(2): 289–308, 2017.

83. Weir PL, Smith KL, Paterson C, Horton S. Canadian women's ice hockey - Evidence of a relative age effect. Talent Dev Excell 2(2): 209–217, 2010.