A scoping review on positional, psychological and physiological characteristics of ice hockey goaltenders

Louis-Philip Guindon

Departmental of Kinesiology and Physical Education

McGill University, Montreal, Quebec, Canada

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List of Common Terms and Abbreviations

HR – Heart rate

RSE – Repeated sprint exercises

RSA – Repeated sprint ability

RPE – Rate of perceived exertion

MVV – Maximum voluntary ventilation

FEV_1 – Force expiratory volume in one second

PFT – Pulmonary functional test

$\dot{V}O_2$ max – Maximal oxygen consumption

NHL – National Hockey League

FAI – Femoroacetabular impingement

RPM – Rhythm per minute

ROM – Range of motion

DEXA – Dual Energy X-Ray Absorptiometry

GPS – Global Positioning System

PCr – Phosphocreatine

ATP – Adenosine triphosphate

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Abstract

Ice hockey goaltenders have been recognized as a highly complex position requiring constant movement performance in extreme range of motion and unique mental coping mechanisms. The literature forecasts goaltenders' related studies in multiple themes. These broad thematic schemes towards the position specialist suggest complexity in goaltenders since numerous topics need to enclose their abilities and characteristics. Therefore, the purpose of this study was to revise the current accumulated knowledge in the field and conduct a scoping review to map the current and available literature, organize the current evidence on the position, and report research gaps to inform the practice of ice hockey goaltenders.

A five steps approach was followed to process the scoping review. A research question was first identified to guide the articles' analysis. Relevant studies were then found through eligibility criteria from both inclusion and exclusion criteria. A structured search strategy was made from five central databases. 472 records were found from the initial search. Ninety-nine studies were included and identified as relevant for the scoping review. Studies were selected, and data from the studies were charted through an extraction strategy reviewed by two authors. Lastly, data were summarized, collated and reported through results with the aim to mapping the key concepts, organizing the evidence on ice hockey goaltenders and reporting research gaps for future research priorities.

Six main themes were identified from the literature on ice hockey goaltenders which indicated a high complexity to the position. The evidence of the included studies suggests early interventions that involve mental and physical training which optimize performance and prolong the careers of goaltenders. Numerous stakeholders can use the evidence of this scoping review for a better application, uniformity and practice of the position specialist. Practitioners and

policymakers can improve the performance of goaltenders by applying the specificity of goaltenders' training regimens and the on-ice demand complexity. Further research investigating movement patterns' demand, specific physiological and psychological assessments, establishing statistical norms of performance, and assessing reference values of strength for injury prevention represent future research priorities.

Résumé

Le gardien de but de hockey est reconnu comme étant une position très complexe nécessitant la performance constante de mouvements à des amplitudes de mouvements élevé et des mécanismes d'adaptation à ses demandes mentales. La littérature présente les études sur les gardiens de but en plusieurs thèmes. Ces thèmes concernant la spécialisation de la position suggèrent sa complexité puisque plusieurs thèmes sont de mise pour informer ses différentes habiletés et caractéristiques. Donc, le but de cette étude est de réviser l'information accumulée actuelle dans ce milieu et visiter la question suivante : Qu'elles sont les lignes directrices et les recommandations pour améliorer la condition physique et les performances sur la glace du gardien de but ?

Une approche de cinq étapes a été suivi pour procéder à cette revue exploratoire de la littérature. La question de l'étude a été identifiée pour guider l'analyse de l'article. Les études pertinentes ont ensuite été trouvé par les critères d'éligibilités par les critères d'inclusion et d'exclusion. Une stratégie de recherche structurée a été établi par cinq principales bases de données. 472 articles ont été trouvés de l'étude initiale. 99 études ont été inclus et identifié comme pertinentes à cette revue exploratoire de la littérature. Les études sélectionnées et données ont été planifié par une stratégie d'extraction revue par deux auteurs. Dernièrement, les données ont été résumé, examiné et rapporté par les résultats et avec l'objectif de faire le plan des concepts clés, d'organiser les évidences sur les gardiens de but et rapporter les écarts de recherche pour prioriser les futures recherches.

Six thèmes principaux ont été identifiés de la littérature sur les gardiens de but ce qui indique une grande complexité à la position. Les évidences des études inclues suggèrent une intervention qui commencent à un jeune âge impliquant un entrainement mental et physique

spécifique à la demande du gardien pour améliorer ces performances et prolonger ces années de carrières. Plusieurs parties prenantes peuvent utiliser les évidences de cette revue exploratoire de la littérature pour une meilleure application, uniformité et pratique de la position. Les praticiens et les responsables politiques peuvent améliorer du gardien de but en appliquant la spécificité du régime d'entrainements de la position et la complexité de la demande sur glace. Les études prioritaires futures devraient examiner la demande physiologique des mouvements sur glace du gardien, des tests spécifiques pour la position, l'établissement des normes statistiques de performance du gardien et l'évaluation de valeurs de références de force physique pour prévenir les blessures.

Preface and Contribution of Authors

Louis-Philip Guindon was the primary author with roles in, data collection, analysis and interpretation, and thesis preparation.

Dr. Ross E. Andersen, Professor, Department of Kinesiology and Physical Education, McGill University, the candidate's supervisor, was actively involved in every step and decision made regarding the research study and the completion of this thesis.

Patrick Delisle-Houde assisted in the manuscript editing

Chapter 1 - Introduction

1.1 Scope of the Problem

Hockey is a very popular sport in Canada, it is estimated that more than 1.3 million Canadians have played the sport (Heritage, 2010). Overall, the sport attracted the same number of participants between 1992 and 2010 (Heritage, 2010), while scientific interest in the sport of hockey has increased exponentially since the 1990's (PubMed.org, 2020). The scientific literature on hockey has mainly looked at the physiological profiles of mainly the skating positions (forward and defensemen), while a small number of studies have reported on goaltenders (Burr et al., 2008; Cox, Miles, Verde, & Rhodes, 1995; Montgomery, 1988). Historically, goaltenders have not been represented in investigations on the physiologic demands of hockey (M. R. Green, Pivarnik, Carrier, & Womack, 2006). Recent studies investigating solely aerobic capacity or anaerobic capacity of hockey players have excluded goaltenders in their sample (Jackson, Snydmiller, Game, Gervais, & Bell, 2016; Stanula, Roczniok, Maszczyk, Pietraszewski, & Zajac, 2014). When studying on-ice testing and evaluating time-motion analysis (Jackson et al., 2016), skating economy (Lamoureux, Tomkinson, Peterson, & Fitzgerald, 2018) and skating tests (Boland, Delude, & Miele, 2019; Lowery, Tomkinson, Peterson, & Fitzgerald, 2018; Peterson et al., 2016; Stanula et al., 2014), investigators only included skating positions in their samples. However, when performing off-ice testing, many investigators have included goaltenders within their sample (Cordingley, Sirant, MacDonald, & Leiter, 2019; P. Delisle-Houde, Reid, Insogna, Chiarlitti, & Andersen, 2017; Leiter, Cordingley, & Macdonald, 2017; Triplett et al., 2018). Off-ice testing is essential for strength and conditioning professionals as they can adapt their periodization strategies and support on-ice demands (Boland et al., 2019).

As goaltenders have unique gear compared to skating positions and both their game demands and on-ice abilities are different, investigators need to construct position-specific protocols. Few studies have observed the movement patterns of goaltenders (Bell, Snydmiller, & Game, 2008) and on-ice assessments evaluating the physiologic demands of goaltenders (Cox et al., 1995; Montgomery, 1988). Recently, McCarthy et al. (2020) analyzed the thermoregulation, heart rate, fatigue, and performance of goaltenders during on-ice movement pattern protocols. These physiological parameters are fundamental to understand goaltenders' demands during their movement patterns. Little is currently known about the physiologic requirements of goaltenders during their on-ice workload. Comprehending the sport-specific physiological demands in goaltenders is essential to optimize performance. The awareness of their movements' demand and the selection of the proper movements according to the opponents' actions may alter fatigue and therefore may amplify overall performance.

Side-to-side and up and down movement are demanding activities in which goaltenders must maintain consistent balance on their skates while being ready to receive a shot at any time. The repetition of these movement patterns throughout practices and competitions places a high demand on both the joints of the goaltenders' body (Whiteside, Deneweth, Bedi, Zernicke, & Goulet, 2015) and their physiological capacities. The on-ice demand for goaltenders can raise their heart rate as high as 180 bpm during practices and simulated scrimmages (McCarthy et al., 2020). Effectively, the combination of the athletic stance, posture, and movement patterns places stress on the body to cope against the demand (Whiteside et al., 2015). It has been suggested that posture is compromised and disrupted during vigorous aerobic and anaerobic athletic tasks (Laaksonen, Finkenzeller, Holmberg, & Sattlecker, 2018). Patterns performed by goaltenders use both energy systems throughout their on-ice demands, perhaps leading to a potential disruption of their posture and alteration of their athletic stance. It has been suggested that balance and posture are influenced and altered with a change in breathing (Nelson & Papich, 2012). Several muscles (i.e., diaphragm, pelvic floor muscles, transverse abdominus) are involved in a non-breathing function to support posture as well as assisting in breathing function (Courtney, 2009). In the situation of high metabolic demand, skeletal muscles that are involved in both breathing and non-breathing need to prioritize breathing. This may result in compromising non-breathing tasks such as postural support and balance (Courtney, 2009). D. J. Paterson, Wood, Marshall, Morton, and Harrison (1987) also proposed that an increase in breathing frequency negatively influenced limb interactions and muscle coordination during a running task. Fabre, Perrey, Passelergue, and Rouillon (2007) suggested a parallel physiological challenge among rowers in which although there was no significant influence in rowing coordination during a hypoxic state; the authors still suggested the observed hypoxic state would alter the coordination of the upper body and breathing patterns. Likewise, the primary physiological on-ice challenges for goaltenders may be to sustain an optimal performance state while dealing with postural alteration, disrupted breathing patterns, and coordination attenuation.

A fatigue state expressed by hypoxia and increased ventilation may decrease one's coordination and technical skills (Dupont, 2014). Thus, an athlete's capacity to onset fatigue is essential for performing at a high level. High ventilatory demand that exceeds 85% of VO_2max could result in fatigue of both the inspiratory and core muscles (T.K. Tong, Wu, Nie, Baker, & Lin, 2014). This fatigue state has been proposed to increase both RPE and breathing frequency while decreasing tidal volume (T.K. Tong et al., 2014). Although the goaltenders' on-ice physiological demands have been under investigation (McCarthy et al., 2020), goaltender's physiological challenge can be interpreted by the capacity to resist fatigue caused by repetitive movements of their movement patterns that may disturb breathing as balance and posture are being affected. Goaltenders still have the requirement to stop their opponents' offensive threats even during physiologically exhausting circumstances. Monitoring the physiological demands of the most use on-ice movement patterns may structure how goaltenders use each of their movements.

The initial assessment of this project was to monitored goaltenders' on-ice physiological demand via wearable sensor technology. Using a Hexoskin vest, the measurement of the breathing patterns and heart rate will be analyzed during on-ice movement patterns of goaltenders. With the support of wearable devices that include internal load measurements, the evaluation of a sports demand to structure physical training and analysis of movements technicality provides a better physiological evaluation of sport specific activities.

This initial assessment and project were interrupted and changed throughout the Master. The Covid-19 pandemic made it difficult to recruit participants, in addition to the upkeep adaptation of government regulations to reduce the risk of spreading the virus. Although, we were able to assess six participants from the pilot study, we were unable to recruit further participants for the approved protocol due to the McGill University Covid-19 policies and therefore the study could not be safely completed. This required revisions to the scope of the research. Altering the focus of the thesis was consequently the option available with the time allocated for completing the Master. The change of focus was also important to reduce the risk of virus transmission for the stakeholders involved with the study, yet it also served as an opportunity to requestion the focus of investigating the unique positional demand of goaltending. Since goaltenders are the most impactful position in the sport while being understudy compared to the skating positions in the scientific literature, a scoping review was then decided to become the focus of the thesis.

1.2 Purpose

The initial purpose of this study was to characterize breathing patterns and heart rate responses adopted during the four patterns most used by goaltenders: T-push, butterflies, shuffles, and butterfly slides. The on-ice assessment will use the Hexoskin Vest when investigating the movement patterns. With the Covid-19 pandemic interrupting the initial focus of the research, the final purpose of this study was to conduct a scoping review to map the current and available literature, summarize and organize the current evidence on the position, and report research gaps to inform the practice of ice hockey goaltenders.

1.3 Rationale

Goaltenders have been displayed in multiple fields in the literature that portrayed their physiological capacity (Montgomery, 1988; Vescovi et al., 2006), their perceptual ability (Panchuk & Vickers, 2006; Panchuk & Vickers, 2009; Panchuk et al., 2017), their risk of injuries (Worner et al., 2020; Worner et al., 2020), the specificity of equipment capacity (Clark et al., 2020) and psychological demand (Cameron et al., 2006; Smith et al., 2020). All of these subjects have been displayed in the literature with unfulfilled follow-up on the position. Generally, the literature presents the goaltender has an unfit individual or requires facing a high demand, both mentally and physiologically. Their movements need to be explosive and rapid throughout games when performing repetitive side-to-side and up and down actions. This high repetition of movement patterns has been suggested to be a risk factor of the development of hip injuries as most of the movement patterns do result in a healthy human hip joint (Whiteside et al., 2015). Historically, goaltenders have reported a high prevalence of injuries (Ryan J. Frayne & Dickey, 2017). A scoping review on goaltenders' demands may help to tailor training regimens and reduce the prevalence of injuries. More to investigate the current literature on goaltenders, mapping the current literature, including the physiological capacity, may help present the positional specificity of goaltending, investigate the current knowledge displayed in multiple themes and present strategies that may help the development of the position adding to its performance. To date, we are not aware of reports reviewing the future line of research for positional requirement development and performance essentials.

However, a recent study made by Marcotte-L'heureux, Charron, Panenic, and Comtois (2021) review physical testing and physiological profiles of the position. This systematic review helped establish a range of assessment results towards goaltenders' physiological capacity and may support determining the best approach of conditioning the position. Benchmark values were also displayed for strength and conditioning coaches. They proposed a major focus on assessing core, grip strength, flexibility and lower limb power. Adding to their finding on the physiological capacity and profile of goaltenders, the findings of our study may help to specifically align the priority of research that needs to be done on goaltender to understand and fundamentally optimize the on- and off-ice training programs of goaltenders, for a healthy and long-term practice of the sport.

1.4 Hypothesis

Initial Objective #1: Explore the influence of the four movement patterns on the breathing patterns and heart rate in elite and subelite goaltenders.

Goaltenders within each group will be challenged during the movement patterns protocol. Participants will experience an increase in their heart rate and breathing patterns during each of the four movement patterns. Physiological stress may be higher for a movement that requires goaltenders to go up and down rather than side-to-side. Therefore, it was hypothesized that a goaltender would experience higher physiological demands during both butterfly and butterfly slides compare to shuffle and T-push. Physiological demands during the movement patterns will include an increase in tidal volume, breathing frequency, heart rate, and RPE scale. Since goaltenders playing at a professional level have better physical conditioning, their focus is mostly on the performance of the next hockey season. Goaltenders, who play at a subelite level, are considered as student-athletes and have responsibilities in a diverse part of their life (i.e., academics), thus typically have less time to focus on their physical conditioning. Therefore, we anticipate a higher physiological response for both the Midget and Junior group compared to the Professional group performing the same movements.

Final Objective #1: Mapping the literature on ice hockey goaltenders

This is the first scoping review made for ice hockey goaltenders. The position is highly specialized and complex. Hence, it was hypothesized that four main themes would be identified when mapping the literature. Since goaltenders can be considered understudied, the current literature presents the position in various subjects. The four main themes that we expect to identify are physiology, psychological, injuries and equipment. We can also anticipate more studies for physiology and injuries related to the positional demand since both of these themes are closely associated. Conditioning for the demand must be performed, and injuries related to the demand may be caused; therefore, scientific interests towards these two themes may be further investigated.

Initial Objective #2: Identify the relation between on-ice assessed variables with off-ice testing variables.

Off-ice testing includes FEV_1, FVC, MVV, VO_2max, anthropometric measures, and body composition. Knowing the linear relationship between HR and VO_2max, we would expect participants who have a higher VO_2max to also have a lower on-ice ventilation and heart rate compared to participants with a lower VO_2max value. We also hypothesized that goaltenders with a higher VO_2max value would have a lower RPE scale value as they have a higher resistance to fatigue compared to goaltenders with lower aerobic capacities. Considering training can increase FEV_1 and FVC (Mazic et al., 2015), it was also hypothesized that both FEV_1 and FVC would inversely correlate to on-ice heart rate, and ventilation rates.

Final Objective #2: Organize evidence on the position and report research gaps

A scoping review establishes a mapping of the current literature and displays ice hockey goaltender literature's volume, nature and principal characteristics. Knowing the anticipated broad thematic property, we expect the literature to organize further evidence on a high level of competition compared to the amateur level. The funding may be more accessible with the eliteness, yet also provide characteristics of the best goaltenders. We, therefore, hypothesized further studies mentioning goaltenders playing in the NHL. More specifically, we anticipate this population's physiological capacity and injuries prevalence to be presented, which aligns with our first hypothesis. Research gaps may be found in amateur hockey and strategies to reduce the risk of injuries related to the demand for goaltending.

1.5 Delimitations

For this study, here are the main identified delimitations:

1. Research articles were limited to French and English.
2. Research articles on ice hockey that includes goaltenders.
3. Research articles that are both quantitative and qualitative.
4. Research articles published between 1970 and February 2021.

1.6 Limitations

Several limitations were identified for this scoping review:

1. A scoping review do not assess the quality of individual studies to investigate formal methodological assessment of the literature. Hence, there may be lack of synthesis cause in a scoping review.
2. Due to the methodological framework of a scoping review, conducting cause and effect is not possible.
3. Error in the interpretation of the studies may have occurred during the screening by lacking control groups, small sample size, context definition.

1.7 Strengths

The scientific literature on goaltenders will be mapped and investigated. All hockey players identified as goaltenders would be in the interest of this scoping review. The finding of this study may stimulate research interests in the field. Mapping the literature will find gaps in the literature, identifying future research interests and orientation. The practice of goaltenders may be altered with the finding of this scoping review by better understanding the needs and requirements of performing at a high level of competition. Goaltenders may benefit from performing at a high level, but sustaining their level of competition with good conditioning to face the demand of goaltending may be a genuine challenge for some athletes. This scoping review will also summarize the current research findings on ice hockey goaltenders for policy makers, practitioners, and other stakeholders involved around the position who may lack time or resources to investigate by themselves.

Chapter 2 – Review of Literature

2.1 Physiological demands of hockey

Hockey has been described as a sport of subsequent bouts of sprint performance (Burr, Slysz, Boulter, & Warburton, 2015; Durocher, Leetun, & Carter, 2008; Montgomery, 1988) that require athletes to have both high aerobic and anaerobic capacities (H. J. Green et al., 2010; M. R. Green et al., 2006; Vescovi et al., 2006). The overall physiological needs of the sport demands hockey players to develop endurance, strength, and power (Montgomery, 1988; Quinney et al., 2008; Stanula et al., 2014). In addition to the physiological demand, Burr et al. (2008) noted that size and coordination were critical, while Twist and Rhodes (1993) found that general agility and hockey specific skills were required for on-ice success. Acquiring specific hockey related skills allow athletes to improve their skating efficiency and shooting ability during their off season for a potential competitive advantage during their season (Lamoureux et al., 2018). Recent findings indicate the prominence of delaying fatigue during repeated sprints exercise (RSE) by increasing skating efficiency (Lamoureux et al., 2018; Peterson et al., 2015). Although hockey has been portrayed as being a metabolically unique sport (Cox et al., 1995), its energy demands have been compared with other repeated sprint ability (RSA) sports (Peterson et al., 2015). During three periods of 20 minutes, skating hockey players (Jackson, Snydmiller, Game, Gervais, & Bell, 2017) perform shifts of high intensity for 30 to 85 seconds and recover for approximately four minutes in between their on ice performance (Montgomery, 1988; Stanula et al., 2014). Their substitution off and on the ice depends on the flow of the game (Jackson et al., 2017) and coaching decisions (Cox et al., 1995; Jackson et al., 2017). The uniqueness of hockey's physiological requirements brought interest to multiple methods of monitoring and tracking the training load of the sport. The development of multiple monitoring technologies may allow further investigation and examination for distinct and comparable positional characteristics between hockey positions.

2.1.1 Aerobic capacity in hockey

Aerobic energy takes place when oxygen is present metabolically via oxidative phosphorylation. As the intensity of graded exercise increases, maximal oxygen consumption ($\dot{V}O_2$ max) is reached when volitional fatigue is achieved. VO_2max can be influenced by the cardiac output (heart rate and stroke volume), blood delivery efficiency of the respiratory system and exercising muscles' ability to consume oxygen. During RSE like hockey, especially during subsequent shifts, ATP through PCr would not likely be able to fully recover (Girard, Mendez-Villanueva, & Bishop, 2010). The ability to perform subsequent sprints while sustaining power requires a well conditioned aerobic system to increase the rate of muscle oxygenation, speed between-shift recovery and minimize fatigue (Girard et al., 2010). The physiological requirements and contributions of skating hockey players during a game have been suggested to have a division of 69% of anaerobic and 31% of aerobic metabolism (Seliger et al., 1972). In addition to the lower energy contribution through the aerobic metabolism, the maximal oxygen consumption is widely assessed in hockey research (M. R. Green et al., 2006; Hoff, Kemi, & Helgerud, 2005; Montgomery, 2006; Twist & Rhodes, 1993). Several techniques have been used to assess the aerobic endurance of hockey players, including cycle ergometers, treadmills and on-ice protocols (Ferguson, Marcotte, & Montpetit, 1969). VO_2max has been linked to increased scoring opportunities (Green et al., 2006) and players on-ice speed interval (H. Green et al., 1976). While an assessment of VO_2max on the treadmill and cycle ergometer lack sport specificity (Durocher et al., 2008), an on-ice skating protocol to assess VO_2max may exclude goaltenders from the assessment. It has also been suggested that hockey players with higher VO_2max have a better buffering effect of H+ during on-ice repeated sprint tasks (Peterson et al., 2015). Combining this with movement economy and muscle oxygen consumption may delay fatigue in young male hockey players (Lamoureux et al., 2018). Whether aerobic capacity of hockey players may be associated or linked with the value of VO_2max, the effectiveness of the oxidative phosphorylation or the aerobic capacity is essential within the demand of the sport. Although, the development of a fit aerobic capacity for the three positions would strengthen oxidative phosphorylation capacity, which may delay fatigue in later sprints during RSE (Girard et al., 2010); Yet, VO_2max is not the only factors who have been shown to be essential during the performance of RSE (Jeppe F. Vigh-Larsen et al., 2020).

One of the main characteristics of elite hockey players is their ability to sprint (Montgomery et al., 1988). RSA in hockey has been associated with lactate threshold (Lowery et al., 2018) and linked a significant relationship between maximum aerobic capacity and fatigue (Peterson et al., 2015). Fatigue, during subsequent bout of sprints, occurred because of the lack of sufficient phosphocreatine resynthesize, glycolysis depletion (Vigh-Larsen et al., 2020) and accumulation of metabolites reducing the muscle power output (Bishop, Girard, & Mendez-Villanueva, 2011; Girard et al., 2010). Other contributors of fatigue may be related to K+ extracellular accumulation, production of reactive oxygen species, hyperthermia and dehydration (Allen, Lamb, & Westerblad, 2008). This accumulation of fatigue over and above aerobic capacity, represented by VO_2max, may influence the recovery rate of hockey players (Cooke, Petersen, & Quinney, 1997). High aerobic capacity allows hockey players to increase their capacity of recovering energy substrates by buffering H+ (Peterson et al., 2015; Roczniok et al.,

2016) and resynthesize phosphocreatine at rest (Peterson et al., 2015; J.F. Vigh-Larsen et al., 2019). Similarly, Glaister (2005) proposed that aerobic capacity plays a significant role in the recovery of RSE. This proposition is linked with Green et al. (2006) who have mentioned that aerobic capacity has a positive relationship with their time on-ice, though this has not been studied in goaltenders. For goaltenders, a higher aerobic capacity may be more effective in their movements and coordination, thus decreasing their chance of allowing a goal due to muscle fatigue. Both skating hockey players and goaltenders can decrease lactate accumulation by having a well-trained aerobic system (Roczniok et al., 2016). Bogdanis, Nevill, and Lakomy (1994) reported that the aerobic system provided 13% of the energy during a 10 second sprint and 27% of energy during a 20 second sprint in active, fit men. As sprints were repeated, the aerobic system provided a major source of the energy and provided a more efficient recovery by resynthesizing PCr and buffering H+ from active muscles to reduce acidity in the muscle (Tomlin & Wenger, 2001). Although the aerobic system is involved for hockey players in their RSA, anaerobic metabolism is the principal energy source that provides high intensity power production during RSE in young active men (Girard et al., 2010).

2.1.2 Anaerobic Capacity in hockey

Both ATC- PCr and the glycolytic system provide energy through anaerobic metabolism. Anaerobic capacity refers to the maximum amount of ATP that is being resynthesized via both available anaerobic pathways glycolysis and PCr (S. Green, 1994). The PCr system, also known as the anaerobic alactic system, is essential for producing an immediate, explosive energy source that is used for RSA (Girad et al., 2010). The anaerobic glycolysis pathway, which converts pyruvate into energy and lactate, is the only source of ATP in red blood cells, making it a vital source of energy for muscles during RSE. Anaerobic glycolysis is required to provide energy after the stores of PCr have been depleted (Tomlin & Wenger, 2001). Six seconds through RSE causes a PCr depletion between 35% to 55% of resting level (Dawson et al., 1997). This lactate accumulation has been related to recovery time and fatigue during a hockey game (M. R. Green et al., 2006) and causes muscle fatigue (Girard et al., 2010). A high number of metabolites, including lactate levels, may also interfere with muscle coordination and, therefore, decrease players' overall performance (Montgomery, 1988). San-Millan and Brooks (2018) reported that during high intensity exercise, lactate production and accumulation is higher in male athletes than in untrained males. Male athletes, having both higher energy expenditure and lactate clearance aptitude, adapt efficiently to their metabolism to use lactate as an energy source (San-Millan et al., 2018). Lactate is commonly known as an end product metabolite resulting from oxygen insufficiency, yet it is a large energy source formed within the glycolytic pathway (San-Millan et al., 2018).

Via both the anaerobic glycolysis and PCr system, anaerobic metabolism is the main energy requirement that hockey players use. Anaerobic power can predict the performance of hockey players in their first shifts of every period (Peterson et al., 2016). Goaltenders use the PCr system when making the first save or clearing pucks from the zone and use glycolysis pathways when the puck is in the zone for longer periods of time, requiring multiple saves (Twist & Rhodes, 1993). Defensemen similarly use PCr for man-to-man situations and glycolysis pathways when the puck in the defensive zone for longer periods of time (Twist & Rhodes, 1993). Forwards, repeatedly performing backchecks and forechecks, require well trained anaerobic glycolysis pathways (Twist & Rhodes, 1993). During simulated hockey shifts, H. Green et al. (1976) reported a depletion of muscle glycogen by up to 70% of their initial metabolic storage. Still, PCr is the main energy source contributing to power development for hockey players (Peterson et al., 2016), contributing to 49% of the total energy demand during RSE (Girard et al., 2010). Especially during RSE, anaerobic is highly active to sustain the energy demand and counter muscle fatigue (Durocher et al., 2008). Muscle fatigue is defined when the task, in this case skating speed, can not be sustained (Girard et al., 2010). Muscle fatigue is linked to the depletion of PCr and a reduction in muscle power and performance of hockey players (Cooke et al., 1997). Muscle fatigue occurs when storage of PCr is depleted, and blood lactate begins to accumulate. During RSE, it has also been suggested that muscle fatigue is also related to oxygen unavailability (Peterson et al., 2015) and the rate of muscle reoxygenation (Girard et al., 2010). Therefore, players with lower oxygen capacities will have more difficulty maintaining their performance throughout the game than players who have higher oxygen capacities (Peterson et al., 2015). When anaerobic power is not fully recovered, hockey players would not be able to perform at the same level they initially did (Peterson et al., 2016). Recovery time between shifts lasts approximately 3 minutes (H. Green et al., 1976), and PCr stores may not be fully restored when returning on the ice, potentially compromising RSA (Girard et al., 2010). The recovery of working skeletal muscle starts with the resynthesis of PCr and removal of hydrogen ions (Sahlin & Ren, 1989). The removal of hydrogen ions allow for the resynthesis of PCr for future muscle contractions (Cooke et al., 1997). Therefore, it is essential for hockey players to quickly restore ATP and clear lactate from the blood. (Potteiger, Smith, Maier, & Foster, 2010). Players need to maintain their fitness throughout the season and optimize fitness during the off season. Anaerobic fitness has been reported to decrease throughout the playing season, with a large drop off occurring during playoffs (Moroščák, Ružbarský, Balint, & Vodicka, 2013).

The identification of physical characteristics that correlate with game performance are fundamental for the structure of off ice training and their effectiveness (Boland et al., 2019). Off-ice training objectives should focus on RSA and recovery from hockey specific physiological demand (Girard et al., 2010). Improving recovery and resisting fatigue would increase the ability to perform anaerobic activity and slow the rate of muscle power reduction throughout RSE (Boland et al., 2019). Although there is no clear evidence that the improvement of glycolytic pathway and glycogenolytic would benefit RSA; Through rapid PCr and glycolysis regeneration, hockey players can gain a competitive advantage by training with a designed program aimed to increase the high anaerobic subsequent demand of hockey (Ziemann et al., 2010). Analysing this athlete-specific physiology is essential to personalize the unique positional sport demand and build a structured periodization (McGuigan, 2014).

2.1.3 Internal and External Load

More emphasis must be placed towards the evaluation of sport-specific and athlete-specific physiology (McGuigan, 2014). Evaluating the requirements and implications of hockey players' physiology would structure the design of strength and conditioning program (McGuigan, 2014). The evaluation of both internal and external loads are valuable measures to quantify the training load and physiological response of the sport (Coutts & Cormack, 2014). External loads are a measure that provide information independently of the athlete's internal characteristics like power output, skating speed, acceleration or Time-Motion Analysis. Internal loads are defined as the physiological stress inflicted on the athlete such as rate of perceived exertion, VO_2max, heart rate or questionnaires (Coutts & Cormack, 2014). The capability and different strategies to quantify players physiological response when playing hockey may improve and facilitate the development of the sport (Perrotta, Held, & Warburton, 2017). Although external load has been the primary method of structuring evaluation assessment (Halson, 2014), internal load may be a more reliable measure. Effectively, physiological stress imposed on players may bring further details when looking at the metabolic response compared to an external measure that does not consider internal processes such as psychological and physiological loads (Coutts & Cormack, 2014).

Evaluating hockey players with off- and on-ice testing looking exclusively at external load like power output, acceleration, speed and TMA (Allisse, Sercia, Comtois, & Leone, 2017; Bond, Bennett, & Noonan, 2018; Cordingley et al., 2019; P. Delisle-Houde, Bonneau, Reid, & Insogna, 2016; Dominik, Lipinska, Roczniok, Spieszny, & Stastny, 2019; A. S. Douglas & Kennedy, 2019) may disregard multiple factors that influence performance. The external load does not consider the genetics or the players' physiology (Coutts & Cormack, 2014). However, this type of training load may allow for a better understanding of gameplay (A. S. Douglas & Kennedy, 2019) and on ice speed and distance characteristics (Allisse et al., 2017; A. S. Douglas & Kennedy, 2019). Although off-ice internal load assessment can lack sport specificity, on-ice internal load can explore relationships among testosterone and cortical concentrations throughout the tasks completed during hockey competition (Fitzgerald, Orysiak, Wilson, Mazur-Rozycka, & Obminski, 2018), isokinetic forces of the quadriceps in elite hockey players (Johansson, Lorentzon, & Fugl-Meyer, 1989), on-ice heart rate (Ulmer, Tomkinson, Short, Short, & Fitzgerald, 2019) and neural drive of soleus and tibialis anterior in hockey players (Kinnunen, Piitulainen, & Piirainen, 2019). Both internal and external load have their distinct value of understanding the players training load off- and on-ice. Therefore, the combination of both assessments may be optimal (Halson, 2014). Despite the fact that forwards and defensemen spend most of their game time gliding, the psychological and physiological demand require a near max HR to compete (Jackson et al., 2017). Compared to subelite hockey players, elite hockey players have a higher peak power, VO2 max and 30 m forward sprint, making them more capable of maintaining their performance level throughout their season (Roczniok et al., 2016). Detraining in the second half of a competitive season enlightened an increased post exercise HR, blood lactate concentration and percentage of body fat (P. Delisle-Houde, Chiarlitti, Reid, & Andersen, 2018). Studies, including both internal and external measures with reliable and valid methods, have a fundamental mixed methods approach that is effective to monitor training program (Coutts & Cormack, 2014). Skating economy has been found to be related to fatigue reduction. This highlights the importance of proper skating technique to optimize on-ice performance (Lamoureux et al., 2018).

2.1.3.1 Heart rate

The heart rate can fluctuate when cardiac nerves are activated, when body temperature is changed or when specific hormones are released (Widmaier, Raff, & Strang, 2011a). An increase in heart rate during exercise is caused by the inhibition of parasympathetic activity and enhancement of sympathetic activity. With an increased load of physical activity, the heart rate increases proportionally as oxygen consumption is elevated. A trained cardiovascular system is especially important during intermittent exercise (i.e. subsequent hockey shift) in which blood flow distribution is challenged. Therefore, heart rate has been used to monitor the aerobic capacity of hockey players (Montgomery et al., 1988). Training allows athletes to have an increase in work capacity without any change in total cardiac output (lowering exercising heart rate and increasing stroke volume) (F. G. V. Douglas & Becklake, 1968).

Hockey typically sustains an average on ice heart rate of approximately 85% and peaking at 90% of their respective maximum heart rate value during a shift (Montgomery et al. 1988; Twist & Rhodes, 1993). Similarly, Jackson et al. (2017) monitored 20 university hockey players and observed an average heart rate more than 90% of their maximum heart rate during their shift time and found no significant differences in the heart rate response between forwards and defensemen. Similarly, Jackson et al. (2016) observed mean heart rates of female hockey players and noticed that they typically reach between 92 and 96% of their maximum heart rate during their shift. Similarly, D. H. Paterson (1979) noticed that youth elite hockey players reach an average of 90% of their maximal heart rate during a shift, peaking at approximately 95%. On the contrary, Cox et al. (1995) telemetered only three hockey players' heart rates and found a range of 126 beats/min to 132 beats/min during a game situation environment while having a range between 140 beats/min to 160 beats/min during a hard practice. Seliger et al. (1972) found an average on ice heart rate to be 152 beats/min for respectively players of the Czechoslovak national team. The underestimation of both values monitored by Seliger et al. (1972) and Cox et al. (1995) can be explained by their game simulation within their study and that could have lowered the demand of real hockey game. The prompt increase of heart rate during a shift of less than a minute of mostly gliding shows the high demand that hockey requires. Oxygen delivery can be problematic throughout the final minutes of a game (Paterson et al., 1979), therefore a trained aerobic capacity is essential as the heart and cardiovascular system pump blood efficiently supplying active muscles, vital organs, respiratory systems, and regulating the temperature of the body. Hockey players who have a lower heart rate when performing the same exercise could be considered better conditioned compared to hockey players who have a higher heart rate (Cox et al., 1995).

Rapid recovery is an essential part of this sport that allows players to quickly recover from their high intermittent sprint performance. Looking at both Seliger et al., (1972) and Jackson et al. (2017) that observed respectively a mean heart rate recovery of 132.5 beats/min and a decrease of 63 to 65% of their maximum heart rate, similar to what Paterson (1979) monitored with a recovery from 60 to 75% of maximal heart rate between shifts. Jackson et al. (2016) observed a heart rate recovery to between 70 and 80 % of maximum between shifts and between 56 and 64% of maximum in between periods.

2.1.3.2 Rate of Perceived Exertion (RPE)

The RPE monitors the retrospective of an athlete's physiological stress perception during exercise (Halson, 2014). To add further information upon internal load, RPE can be combined with heart rate or VO_2max to help interpret exercise intensity (Halson, 2014). The perception of one's effort is a combination of information received by muscles, central nervous system, cardiovascular and respiratory system (Borg, Hassmen, & Lagerstrom, 1987). RPE scale provides the subjective symptoms and allows for the quantification of exertion (Borg et al., 1987). There is a significant association between RPE and muscle lactate levels during exercise (Borg et al., 1987). However, Durocher et al. (2008) suggested that RPE was not an indicator of blood lactate accumulation during on-ice exercise as blood lactate increases exponentially during physical activity. Still, the relationship between RPE and performance measures during RSE has been proposed to display mental fatigue, physical fatigue, and a loss of power output (Laurent, Fullenkamp, Morgan, & Fischer, 2014). In addition, to indicate the athlete's degree of physical strain (Borg et al., 1987), RPE may add additional information when combined with the other assessment variables: HR and VO_2max.

2.2. Positional characteristics of goaltenders

Hockey demands goaltenders to perform subsequent lateral movement and reacts on quick released shot by wearing 20 kg of protective equipment (Ryan J. Frayne & Dickey, 2017). They stay inactive for a certain amount of time when the game does not play around them and require performing a subsequent period of high intensity activity (Epstein, McHugh, Yorio, & Neri, 2013). This unique position is highly specialized and athletes need to be technically agile, have fast reaction time, make hasty side-to-side movements, and have highly developed hand-eye coordination (Bell et al., 2008; Epstein et al., 2013). Within the three positions in hockey, goaltenders can have the highest impact when the game engages around the defensive zone. Their main objective is to keep the puck outside the net while facing an attack from the opponent. Goaltenders at elite levels need to save shots that travel over 160 km/h often coming from a close distance (Panchuk & Vickers, 2006). Elite players' shots are exceeding the capacity of the human eye to follow the puck thoroughly, increasing the level of difficulty to perform at that position (Panchuck & Vickers, 2006). Although elite goaltenders often face around 30 shots per game at different angles and levels of difficulty, they are mostly able to save more than 90% of shots (League, 2020). This unique position develops visual motor strategies to perform within an open sport (Panchuk, Vickers, & Hopkins, 2017). They used peripheral vision strategies and cues from the shooter to anticipate the direction of a shot (Panchuck & Vickers, 2006). A focused gaze is vital for goaltenders as they coordinate their body movement with the shooter's movements throughout their release (Panchuck et al., 2017). Even during puck flight, goaltenders can modify their action if they misinterpret the shot from their initial analysis (Panchuk & Vickers, 2009). A longer fixation and initial focus are essential to make the save as the puck flight usually does not change its initial trajectory once it leaves the stick (Panchuck et al., 2017). Puck tracking is essential to make the save voluntarily as goaltenders mostly need to track the puck location two seconds before the release to analyze the shooter's movements and maintained gaze during puck flight (Panchuck et al., 2017). This all combines to have a direct influence on every shot being a save or a goal, goaltenders skill can have a remarkable impact on the overall outcome of the game (Cox et al., 1995) and success of a team (Bell et al., 2008). Being involved in fast decision making, and self-motivated ability (Bell et al., 2008), the mental strategy of goaltenders is essential to come back and reset after allowing a goal (Rogerson & Hrycaiko, 2002). As they cannot leave the ice after allowing a bad goal, refocusing is essential to perform well at this position (Rogerson & Hrycaiko, 2002). Cameron, Cameron, Dithurbide, and Lalonde (2006) proposed that goaltenders have unique personality traits in which they would represent themselves as having high levels of conscientiousness. The fact that goaltenders must stay in their net during a hockey game generally leads to lower team identification compares to forward and defensemen (Cameron et al., 2006).

In addition to having a mental strategy to perform well, goaltenders also need to physiologically adapt and train their body with the demand for their position. Bell et al. (2008) proposed the need for different types of fitness requirements, based on the hip’s range of motion, speed and agility for goaltenders. As they need to react quickly through a large range of motion, the development and sustainability of flexibility is an essential characteristic (Vescovi et al., 2006). Although it has been proposed that goaltenders specific skills need to focus on flexibility, hand eye coordination and reaction time to perform at an elite level, physiological capacity including both aerobic and anaerobic capacity are vital to delay fatigue, uphold a focus during physical stress and avoid injuries (Burr et al., 2008). They need to have the physical conditioning to effectively and technically achieve up and down and side to side movements throughout the entire game (Bell et al., 2008). They require, at an elite level, to be explosive and rapid during games when performing repetitive side-to-side movements like butterflies, T-push, shuffles, and butterflies' slides. These four movements are the most frequently used by the NHL goaltenders during games of the regular season (Bell et al., 2008). Mostly, they relatively achieve the same frequency and types of movements during every period (Bell et al., 2008). Their movement patterns are a highly demanding activity that require goaltenders to keep consistent balance on their skates while being ready to receive a shot at any time. These movement patterns and athletic abilities are harder to perform on the ice (Bell et al., 2008). The athletic stance of goaltenders can vary as it depends on the style imposed by the athlete (Bell et al., 2008). Some keep their knees closer together, while others opt for a wider stance (R. J. Frayne, Kelleher, Wegscheider, & Dickey, 2015). Movement patterns are prepared by the athletic stance and returned to within each game situation involving the goaltender (Bell et al., 2008). This stance helps them move laterally and sustain balance throughout their movement patterns (Frayne et al., 2015).

2.2.1 Physiological demands of goaltenders

Goaltenders perform quick repetitive movements making this position rely mostly on adenosine triphosphate phosphocreatine energy system, and during more prolonged static positions they will rely more on the anaerobic glycolysis system (Twist & Rhodes, 1993). Lactic acid would accumulate during this more prolonged athletic stance hold and when numerous saves need to be made in a short period (Twist & Rhodes, 1993). Compared to skating positions; goaltenders showed small elevation of blood lactate (Montogmery, 1988). Similar to skating positions, goaltenders recover with their aerobic system to be fully prepared when the next opponent offense arrives (Twist & Rhodes, 1993). It has been proposed that VO_2max is not a tool for positional profiling (Vescovi et al., 2006), suggesting for all positions in hockey, the sport is intermitting, relying mostly on anaerobic capacity during shifts and aerobic for recovery (McCarthy et al., 2020).

The ability to focus on the puck has been suggested to be essential upon the physiological readiness of goaltenders, which would prepare their body to react from the speed of the shot (Panchuck & Vickers, 2006). A shot can be stopped by specialized equipment that protect goaltenders from the opposing players' physical contact and the puck (LaPrade, Wijdicks, & Spiridonov, 2009), and it is therefore geared to prevent the team from scoring (Bell et al., 2008). This protective equipment may place a thermoregulatory challenge upon the player and may increase the sweat rates and place an additional physiological demand on the athlete while performing (McCarthy et al., 2020). It has been suggested that goaltenders are susceptible to mild dehydration during competition and must hydrate themselves to reduce fatigue (McCarthy et al., 2020). Dehydration of more than 2% of body mass may cause a decrease in cognitive focus, anaerobic, and aerobic capacity (Frayne et al., 2017).

Goaltenders have shown to be more flexible in the trunk (Montgomery, 1988), hamstrings, and lower back compared to skating positions (Vescovi et al., 2006). Also, Montgomery (1988) presented results of eye span tests that place NHL goaltenders and NHL all star players to perform more than the average NHL players on this ocular test. Physical testing portrayed goaltenders as a hockey player with weak upper body strength, low leg power output, low anaerobic capacity, and higher total fat percentage compared to the two skating positions (Bell et al., 2008; Burr et al., 2008; Vescovi et al., 2006). These lower values of physical testing may suggest how upper body strength is of secondary importance for goaltenders (Vescovi et al., 2006). The low values of goaltenders' physical testing may suggest their unique positional demands apart from the measure of power, strength, and endurance (Burr et al., 2008).

2.2.2 Injury prevalence of goaltenders

The use of highly specialized movement patterns places a high load and stress on modern goaltenders (Mehta, Nwachukwu, & Kelly, 2019). The development of new technical movements like the butterfly and the reverse "V-H" put further load on the hip joint compared to the traditional stand-up way of goaltenders (Worner, Clarsen, Thorborg, & Eek, 2019). In addition to the high lower body demand caused by on-ice movement patterns (Pierce et al., 2013), goaltenders are also at high risk of contact injuries with other players (LaPrade et al., 2009). As they need to locate the puck and make a potential save, they become vulnerable and at a disadvantage for both a voluntary and involuntary collision (LaPrade et al., 2009). This position is highly susceptible to risk of injury, especially overuse injury (R. J. Frayne et al., 2015; Tramer et al., 2015). Compared to the other positions, they use a unique set of movements that increase the rates of hip injury (Pierce et al., 2013). The most common overuse injuries in goaltenders is FAI (Mehta et al., 2019). FAI is the result of repetitive contact between the femoral head and the acetabulum area (Whiteside et al., 2015). FAI can cause more hip complications like labral tears and dysplasia (Mehta et al., 2019). These hip injuries are caused by repetitive movements that required goaltenders to go into large internal hip rotation and force the hip joints in maximal range of motion (Wijdicks, Philippon, Civitarese, & LaPrade, 2014; Worner et al., 2019). Compared to the skating positions, goaltenders would have the highest incidence rate for hip injuries since the position places a high demand on hip flexion and internal rotation (Epstein et al., 2013). The athletic stance, posture, and movement patterns of that position do not follow a healthy human hip joint development (Whiteside et al., 2015). It was proposed that goaltenders' on-ice practice may have an inverse relationship with health with the high prevalence of hip injuries (Frayne et al., 2017). In addition to the load by the butterfly technique, lateral movement patterns require a period of deceleration that also puts a high internal rotation on the hip (Whiteside et al., 2015). Recovering from a save involves hip flexion, adduction, and internal rotation (Whiteside et al., 2015). As fatigue occurs (Pierce et al., 2013), both hip flexion and internal rotation have been suggested to be the leading cause of hip injuries among goaltenders (Frayne et al., 2015; Whiteside et al., 2015). Specifically, the repetitive movement of hip internal rotation puts the athlete at high risk of hip injuries (Whiteside et al., 2015). The high speed of side-to-side puck movement in hockey may place further hip stress on goaltenders both during practice and games (Frayne et al., 2015). It has been suggested that the recovery of the butterfly technique also applies a higher rate on hip flexion and extension when using a two-leg recovery instead of one leg recovery (Frayne et al., 2015). Preventing, reducing, and modifying the use of movement patterns while performing may hinder goaltenders to effectively use the proper technique to make saves (Whiteside et al., 2015).

The current construction of goalie pads has been intended to reduce overall stress on goaltenders' lower body and increase stability while using the butterfly technique (Frayne et al., 2017). Although new goalie pads may reduce the stress on the lower body, the prevalence of FAI and hip injuries will remain high on goaltenders. In addition to the high frequency of hip joint related injuries, goaltenders are also at risk of adductor muscle strains, core muscle related injuries and hip flexor injuries (Mehta et al., 2019). Strong and flexible adductor muscles are a fundamental part in the performance of on-ice movement patterns as their main function is to stabilize and support the pelvis (Methta et al., 2019). Similarly, goaltenders heavily rely on both hip flexor muscles (i.e.: iliopsoas) and core muscles. Both core muscles and hip flexors injuries are caused by the high reliance over these muscles and the repetitive movement patterns that require goaltenders to reach maximal range of motion in an abrupt and changing sport environment (Mehta et al., 2019). A proposed prevention would be to train core muscles that involve gluteus medius, maximus, iliopsoas, and deep hip rotators muscles (Pierce et al., 2013). As it is one of the primary muscles that influence hip, lower back, and knee functions, the conditioning of the gluteus medius is significant for goaltenders (Pierce et al., 2013). Therefore, glutes muscle training may have a significant impact on the rehabilitation protocols of goaltenders (Pierce et al., 2013) and may be necessary during performance and preventing hip related injuries and muscles injuries. Practicing this position consistently puts a high demand on both the hip and the knees; structured conditioning of the lower body, especially of the gluteus muscles, is essential for the longevity of this position's practice. Another suggestion to prevent injuries would be to limit specific goaltenders' movement patterns such as the butterfly technique (Worner et al., 2019). However, reducing movement patterns may be difficult considering the high implementation and utilisation of the butterfly technique. Although the biomechanical unique demand of goaltenders has been investigated, and preventive methods have been proposed both to strengthen lower body muscles and restrict movement patterns, investigating the physiological demand of goaltenders may discern alternative strategy to prevent the high biomechanical load of that position.

2.3 Anatomy and Physiology of Breathing in relation to Exercise

Breathing is a vital variable that may have a significant impact on the performance of athletes. The American Thoracic Society/European Respiratory (2002) illustrated ventilatory demand and capacity are dependent from an individual lung function, respiratory muscle function, and ventilatory control. Involving physiological and anatomical processes, the primary function of the respiratory system is to efficiently exchange gas (Widmaier, Raff, & Strang, 2011b) through inspiration by taking air into the lungs and expiration by removing air from the lungs. Ventilation or the breathing pattern is the result of the tidal volume (V_T) multiplied by the breathing frequency (f) (Widmaier et al., 2011b). At rest, standard resting inspiration contracts the diaphragm and external intercostal muscles, which expands the thoracic cavity. The passive recoil of the lungs effectuate expiration, yet this movement can also be forced by the rectus abdominus and internal intercostal muscles (Mateika & Duffin, 1995). During exercise, three primary respiratory responses are progressively occurring: the initial increase of ventilation to match the metabolic changes, a continuous increase of ventilation during exercise to enhance the uptake of oxygen and eliminate the amount of carbon dioxide and stable elevated ventilation to match the metabolic rate requirement (Mateika & Duffin, 1995). This increase and control of ventilation during exercise is necessary to balance the partial pressure of both oxygen and carbon dioxide and H+ concentrations (Widmaier et al., 2011b).

Wells and Norris (2009) outlined four limitations where the respiratory system is obstructed to its normal physiological functions: work of breathing, respiratory muscle fatigue, arterial hypoxemia, and breathlessness (dyspnea). Work of breathing is caused during high intensity exercises when total body oxygen consumption increases, resulting in increased oxygen uptake of respiratory muscles (Dempsey, Romer, Rodman, Miller, & Smith, 2006). Approximately 15% of the cardiac output goes directly to the respiratory muscles (Harms et al., 1998) and provides sufficient blood flow to the diaphragm. (Romer et al., 2008). Sharing blood flow between active muscles and respiratory muscles may cause diaphragmatic fatigue (Harms et al., 1998) and force the recruitment of secondary respiratory muscles leading to even more blood flow directed towards that area resulting in less to the active muscles (Romer et al., 2008). Respiratory muscles may fatigue, which would increase the sympathetic nervous system that triggers vasoconstriction and may ultimately decrease blood flow to active muscles (Wuthrich, Notter, & Spengler, 2013). With respiratory muscles being fatigued, inhibition of blood flow, and greater oxygen demand in active muscles all result in a reduced capacity to perform (Romer et al., 2008). The energy metabolism to sustain a high demand is represented by the amount of blood flow traveling to the active muscles (Romer, McConnell, & Jones, 2002).

2.3.1 Impacts of breathing in sports

Altering fatigue by increasing both aerobic and anaerobic capacity may attenuate the four limitations of the respiratory system (Wells & Norris, 2009), especially during intermittent exercises (Nicolo et al., 2017). RSE increases the accumulation of lactic acid, which results in the respiratory system increasing the rate of ventilation and causes a concomitant increase in RPE (Romer et al., 2002). Higher maintenance of RSA has been associated with a reduced RPE in active men (T. K. Tong, Fu, Quach, & Lu, 2004). A reduced RPE and increased athletic performance have been reported to be positively associated with inspiratory muscle strength (Romer et al., 2002). Endurance is essential to maintain performance as fatigue may cause weakening of technical skills and therefore movement efficiency (Dupont, 2014). Movement efficiency has been suggested of being proficient at achieving stable movement in wide ROM (Ranson & Joyce, 2014). Technical skills and performing wide ROM have been suggested to be an important characteristic for goaltenders (Bell et al., 2008). A fatigue state expressed by hypoxia and increased ventilation may however inhibit goaltenders' ability to perform their technical skills. Their high reliance on core, glutes, and hip flexors muscles may influence and harden their ability to maintain and sustain their movement patterns throughout the game especially during periods of high ventilation.

High ventilatory demand that exceeds 85% of VO_2max can fatigue both inspiratory and core muscles (Tong et al., 2014). This fatigue state has been found to increase both RPE and breathing frequency while decreasing tidal volume (Tong et al., 2014). Core muscles have been proposed to have valuable functions in keeping a stable and upright posture (Tong et al., 2014). A controlled trunk position, in conjunction with the pelvis, may enhance athletic performance by transferring energy efficiently through the extremities of the body (Kibler, Press, & Sciascia, 2006). The capacity to stabilize the trunk with the pelvis incorporates the involvement of diaphragm and core stability (Nelson & Papich, 2012). Stephens et al. (2017) suggested diaphragmatic breathing activity as a positive factor of balance by involving deep core muscles and proprioceptors. The role of posture becomes crucial in sport considering that while respiratory demands increased, the diaphragm prioritizes its role to breathing over stabilizing the posture (Hodges, Cresswell, & Thorstensson, 1999; Nelson & Papich, 2012). Through the maintenance of postural balance on an ice surface while playing hockey (Hrysomallis, 2011) or harmonizing postural stability with shooting accuracy while being fatigue in biathlon (Laaksonen et al., 2018), the connection between posture, athletic ability, and breathing patterns are required to achieve movement efficiency and consequently optimize performance.

Breathing pattern is regulated during exercise to minimize the work of breathing caused by the respiratory system (Romer et al., 2008). Through RSE, inspiratory muscles and core muscles are able to work together to control postural stance while enhancing the rate of respiration (Tong et al., 2014). Performing their movements with the puck left to right while sustaining an athletic balanced stance, goaltenders may disrupt this stability during a potential save. One of the challenges goaltenders face is to save the puck while maintaining and repositioning their stable athletic stance. Improvement in sport-specific balance can inhibit the visual support for sustaining a stable athletic stance, therefore increasing the attention for other sensory input (Hrysomallis, 2011). In other words, having an increased balance ability, goaltenders can place their attention further on the puck localization. Recently, Boland et al. (2019) assessed hockey players for both the forward and defense position and excluded goaltenders in the sample to investigate inspiratory muscle strength. Through the maximum inspiratory pressure, inspiratory muscle strength has been shown to support aerobic capacity when performing anaerobic type activity in skating positions (Boland et al., 2019). During RSE, fitter inspiratory muscle has also been proposed to improve recovery and lower blood lactate accumulation (Romer et al., 2002). Respiratory muscle strength has been evaluated using maximum inspiratory pressure through diaphragmatic EMG (Hajghanbari et al., 2013), PFT and MVV (Mazic et al., 2015).

2.3.2 Sports relational to PFT and MVV

MVV has been used to investigate respiratory muscle endurance in athletes and young adults (Sales et al., 2016). MVV is a volitional measure that monitors the maximal capacity of breathing, yet it is not measured during exercise (Beam & Adams, 2014). MVV relies mostly on the anaerobic alactic system for the primary energy source to accomplish the test (Sales et al., 2016). This short duration assessment involves subsequent contraction of both inspiratory and expiratory muscles (Sales et al., 2016). Lumb (2017) noted the high correlation of VO_2max with MVV and commented that young adults could only sustain approximately 70% of their MVV while performing at maximal exercise; yet this percentage can be increased by training. Effectively, MVV has been previously reached by competitive cyclists by reaching as far as 90% of their MVV (Lucia, Carvajal, Calderon, Alfonso, & Chicharro, 1999). This high reaching value may represent their ability to significantly reduce their ventilatory demand by having a high exercise ventilation capacity (Beam & Adams, 2014). Although MVV results and investigation is dependent on the athlete's performance and effort in addition that it may not represent the similar exercise response on the ice; yet MVV can be a reliable and useful tool to compare goaltender's respiratory capacity. Mazic et al. (2015) also proposed that a higher PFT can be trained by regular swimming practices that showed an improvement in respiratory function as the lungs and chest wall adapt with water to the aerobic demand activity. HajGhanbari et al. (2013) summarized inspiratory muscle training and found an increased FEV_1 value in a broad range of athletes, suggesting their capacity to reduce their airflow limitation. On the contrary, Hagberg, Yerg, and Seals (1988) did not demonstrate an improvement in PFT among younger individuals. However, they cited Leith and Bradley (1976) that concluded an improvement in vital capacity, total lung capacity and MVV respectively when practicing an aerobic training program.

2.4 Wearable devices in sports

Over time, there has been enhanced importance upon monitoring the training response and load received by athletes in their sports (Coutts & Cormack, 2014). Understanding the physiological effects of the training load is essential to tailor training programs to enhance performance (Coutts & Cormack, 2014). Quantifying one’s ability and performance have recently become possible with the growing trend of wearables devices (Aroganam, Manivannan, & Harrison, 2019). Wearable technologies have evolved through time and may contain multiple components to accommodate the user’s needs (Aroganam et al., 2019). Microcontrollers, accelerometer, gyroscopes, magnetometers, GPS, heart rate sensors, pedometers, Bluetooth communication and pressure sensors can now make specific monitoring feasible (Aroganam et al., 2019). The investigation of players' performance in team sports settings during practice and competition has been developed with the technology of GPS in wearable devices (Cummins, Orr, O'Connor, & West, 2013). Within multiple team sports, Cummings et al. (2013) concluded that GPS has acceptable reliability and validity to assess external load at lower speeds. This type of technology has been used within a broad range of team sports including rugby, football, soccer, cricket, and hockey (Cummings et al., 2013). The measurement of player movements has been useful to quantify the different positional workloads in multiple team sports and investigate the levels of RPE (McLellan, Lovell, & Gass, 2011). Quantifying the internal load as the primary training load better represents the fitness outcomes with which athletes have been stressed compared to the external load (Coutts & Cormack, 2014). Research that has only investigated the locomotor demands of a team sport underestimates the actual physiological demand of the sport on one's body (Chambers, Gabbett, Cole, & Beard, 2015). Wearable devices that include internal load measurements make it possible to evaluate a sport's demand to structure physical training and analysis of movements technicality and a better physiological evaluation of sport specific activities. Sport-specific tests and assessments are essential to understand the specific physiological demands of a sport (McGuigan, 2014). Evaluating these sports' demands becomes identifiable and accessible with wearable technologies such as the Hexoskin skin vest (Elliot & Hamlin, 2019). This type of vest allows for the measurement of breathing patterns, as well as heart rate at rest, and during exercise (Smith et al., 2019).

2.4.1 Hexoskin

The Hexoskin Vest is a wearable device that monitored multiple physiological parameters, including both external and internal load. Multiple sensor measurements include breathing frequency, tidal volume, and HR (Villar, Beltrame, & Hughson, 2015). Monitoring a specific task using the Hexoskin Vest is challenging as the skin needs to have continuous contact with the chest and abdomen sensors. (Elliot & Hamlin, 2019). Therefore, a task that requires frequent upper body movements and increased aerobic demand may remove the contact between the skin and the sensors (Elliot & Hamlin, 2019). However, the Hexoskin Vest has fabric (73% polyamide microfibers, 27% elastane) that limit these noise and contact issues, assuming the vest has been well fitted (Villar et al., 2015). Its validity and reliability to monitor internal load variables have been shown to be high when assessed at a submaximal intensity ranging from 50 to 75% of the work rate maximum (Elliot & Hamlin, 2019). Correspondingly, during cycle ergometer protocols in a different climate from low physical intensity to high physical exertion, there were no significant differences in heart rate readings between a Polar® monitor and a Hexoskin Vest when performing an outdoor cycling task (Al Sayed, Vinches, & Hallé, 2017). HR and breathing frequency are shown to be the accurate and valid measurements from the Hexoskin Vest as they are directly monitored through ECG signal and respiration sensors from the rib cage and abdomen (Cherif et al., 2018). Elliot et al. (2019) compared laboratory assessments of HR, breathing frequency and minute ventilation to the Hexoskin Vest monitored values and found high validity results for both HR and breathing frequency while performing a cycling task. From rest to near maximal intensity task, the Hexoskin Vest is a great tool to observe the physiological demand during sports tasks and may bring further information to the design and implementation of a training program.

Chapter 3 – Methods

3.1 Scoping Review

A scoping review was established for this project to integrate various research findings on goaltenders and gain an accessible understanding of the position. Since the position of ice hockey goaltenders is complex, a scoping review is of use to identify research gaps and present known research findings. The five-stage scoping review process outlined by Arksey and O'Malley (16) was used to process this scoping review. Adaptions were incorporated to this process from Levac et al's framework (17), the Joanna Briggs Institute and previous published scoping reviews (18-20). This scoping review followed and completed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-Scoping Review (ScR) checklist to structure the methodology of the paper (21).

3.2 Identify the research questions

Goaltenders have primarily been investigated as hockey players, yet distinctively examining the goaltenders from a specialized position requires organization. The literature forecast goaltenders' related studies in multiple themes. These broad thematic schemes towards the position specialist suggest complexity in goaltenders since multiple topics need to characterize the abilities and characteristics of this unique position. Although the current broad thematic schemes may hinder the interpretation of the position's optimal training regimen and preparation, an opportunity to review the broad characteristics can inform various stakeholders (i.e., team's owners, coaches, teammates, physicians, team, policymakers). The game of hockey would be further up-to-date in determining the high level of proficiency of the position specialist that has been subject to less scientific attention. The first mentioned papers of ice hockey goaltenders were published in the 1970s (22, 23), and to our knowledge no review has addressed the goaltender position's advancement and current founding. Numerous papers have investigated goaltenders as hockey players and less as a position specialist. With the current accumulated knowledge in the field, it is essential to visit the following question: What are the current guidelines and recommendations to improve physical condition and on-ice performance of goaltenders?

3.3 Identifying relevant studies (Eligibility criteria)

Relevant studies were identified and filtered through inclusion and exclusion criteria. These criteria were based on previous research papers and discussed by the authors scoping review in detail. This scoping review has been prepared to include all hockey studies that incorporate goaltenders within their group sample. Inclusion criteria include: Research articles that were not limited by geographical location or settings of the study; Research articles that were limited to English or French; All age, sexes and level of competition (i.e.: Recreational, Elite) were included; Ice hockey studies that included goaltenders in their analysis; Outcome variables had to be health-related to maximize performance, rehabilitative interventions, psychological aspects specific to the position or physiologically based; Studies that were published between 1970 and February 2021; and qualitative research. Exclusion criteria include: opinion works, magazine and newspaper articles; and on-ice hockey studies that excluded goaltenders from their protocols or dataset.

Thereafter, a search strategy was established to assemble and identify the set of studies that would be examined for the scoping review. A search was made (February 1st, 2021) with a central database that included SportDiscuss, Scopus, WebofScience, PsychInfo and MEDLINE for relevant published literature. A similar searching strategy was used in each database. Since the literature on ice hockey goaltenders is specific but broad, all relevant studies were reviewed. The search included "hockey" as the main keyword with term related to goaltender. The search on the five-database used hockey AND (goalie* OR goalkeeper* OR goaltender*). The search strategies were reviewed and we consulted with a research librarian from the McGill University Life Sciences Library.

3.4 Study selection

Titles and abstracts were collated and investigated by the first author who screened full-text articles for eligibility. The first author shared the eligible sources for review by a second author. Full articles that were considered eligible via inclusion criteria were sourced. The first author then performed the independent investigation, referring via inclusion and exclusion criteria. If uncertainty and/or disagreement on a study's eligibility came up, a consensus was discussed with the third author for final decision. Authors were contacted for full texts when not available or for inclusive language (i.e.: French, English). Despite browsing via McGill University library databases, connecting with authors and requesting text from the University's Central Interlibrary Loan Service, 15 were not able to be sourced and 7 were limited by foreign language. As seen in Figure 1, 41 papers were reported as not relevant, while 6 were added through other sources since they were deemed to be relevant.

3.5 Charting the data

Data extractions were created by the first and second author. A sample of the first 5 studies were independently extracted from both authors and examined to assess the extraction strategy for consistency in answering scoping review's questions. The first author extracted the majority of data, while the second author reviewed 10% of the extracted data for a quality check. Information was input within a consistent analytical procedure for all the chosen research. Information was recorded as follow: Author(s); Year of publication; Origin (Place of investigation); Aims/Purpose; Study population and sample size; Methods, Research Design Type; Data collected (i.e., Questionnaires, Heart rate); Outcomes and details related to results; and key findings related to scoping review questions.

3.6 Collating, summarizing and reporting the results

Descriptive data and main findings were summarised and examined for critical analysis. Results are presented numerically and thematically based on qualitative and quantitative data analysis. A quantitative analysis was performed on the data to display common themes, the period of publication and study methods. A thematic analysis was also described to present how the current research displays the scoping question within the literature. A consistent approach was taken for both qualitative and quantitative data. The standard approach was used to display the primary characteristics, key concepts/evidence developed, and research gaps identified. With this scoping review, we aim to map the key concepts and findings on ice hockey goaltenders, summarise and organise the evidence in a practical approach for health care practitioners, exercise physiologists and coaches and report research gaps in the current literature on ice hockey goaltenders that require further inquiry and future research priorities.

The initial search found 472 studies, after duplicates were manually excluded, 245 records remained. From the remaining studies, 111 were identified to not meet inclusion criteria. From the 134 reports assessed for eligibility, 41 were found to be irrelevant ensuing to a full text review. Six supplemental studies were added following searches, authors' discussion and references. In summary, 99 studies were included and identified as relevant to answer this scoping review's aims and foremost question ‘What are the current guidelines and recommendations to improve physical conditioning and on-ice performance of goaltenders?’

Chapter 4

Manuscript 1

A scoping review on positional, psychological and physiological characteristics of ice hockey goaltenders

Louis-Philip Guindon, Patrick Delisle-Houde & Ross E Andersen
McGill University, Department of Kinesiology and Physical Education, Health and Fitness Promotion Laboratory, Montreal, Quebec, Canada.

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ABSTRACT

Objective: To scope the evidence on ice hockey goaltenders. **Design**: Scoping review**. Data sources**: Published and unpublished reports starting from 1970, identified by researching databases and reference lists. **Methods**: A stage of three research strategies was used to identify relevant studies, secondary studies and grey literature. Identified studies were screened and included with inclusion criteria. Data were analyzed and pulled out via standardized tools to develop a descriptive analysis and thematic summary. **Results and Discussion**: 472 records were found from the initial search. Ninety-nine studies were included and identified as relevant for the scoping review. Numerous themes among ice hockey goaltenders were identified from the literature and suggest a high complexity to the position. The evidence of the included studies suggests early structure and involvement in goaltenders' development for career longevity, specific training interventions and requirements for optimal performance. **Conclusions**: Numerous stakeholders can use this evidence for a better application, uniformity and practice of goaltenders. Practitioners and policymakers can improve the performance of goaltenders by applying the specificity of goaltenders' training regimens and the on-ice demand complexity. Further research investigating movement patterns' demand, and specific physiological and psychological assessments as well as establishing statistical norms of performance and assessing reference values of strength for injury prevention represent future research priorities.

INTRODUCTION

In Canada, ice hockey is the premiere sport (1) with more than 600 thousand Canadians engaged in the sport between 2019 and 2020 alone (2). Ice hockey attracted the same number of participants between 1992 and 2010 (3), while general interest in the sport has increased exponentially since the 1990's (4). Hockey puts the athlete in a complex environment that is physically demanding and requires specific fitness capacity to achieve a high level of performance (5-7).

Among all the players, goaltenders have been identified as a vital variable for success in hockey (5, 8, 9), having the prospective opportunity to save every shot and consequently control the score and the outcome of the game (8). The goaltender has been identified as a position requiring distinct gear, unique game demands and on-ice abilities (10) and has been recognized as one of the most demanding positions in professional sports (11). Being in a team environment, goaltenders must remain distinct in its training regimens due to his specific on-ice demands. Since goaltenders have been subject to a high injury rate against both acute noncontact and contact scenarios (12), sustaining health and longevity in goaltenders is essential for both athletes and teams. Strategies for positional prerequisite have not been clarified adding to the exposure of injuries within the sport (12, 13), goaltenders are practicing without be acquainted with the potential injuries related to their specific demand (13).

Despite the value of goaltenders, the scientific literature has mainly focused on physiological profiles of skating positions (forward and defensemen), while a small number of studies have reported on goaltenders specifically (5, 14, 15). Goaltenders have primarily been investigated as part of entire hockey teams, yet distinctively examining the goaltenders from a specialized position is a priority. The literature forecast goaltenders' related studies in multiple themes. These broad thematic schemes towards the position specialist suggest complexity in goaltenders since multiple topics need to enclose its abilities and characteristics. Although the current broad thematic schemes may hinder the interpretation of the position's optimal training regimen and preparation, an opportunity to review the broad characteristics can inform various stakeholders (i.e., team's owners, coaches, teammates, physicians, team, policymakers). The game of hockey would be further up-to-date in determining the high level of proficiency of the position specialist that has been subject to less scientific attention. Therefore, the purpose of this study was to conduct a scoping review to map the current and available literature, summarize and organize the current evidence on the position, and report research gaps to inform the practice of ice hockey goaltenders.

METHODS

The five-stage scoping review process is outlined by Arksey Arksey and O'Malley (16) was used to process this scoping review. Adaptions were incorporated to this process from Levac et al's framework (17), the Joanna Briggs Institute and previous published scoping reviews (18-20). This scoping review followed and completed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-Scoping Review (ScR) checklist to structure the methodology of the paper (21). Each stage of the scoping review approach is described below.

Stage 1: Identify the research questions

The first mentioned papers of ice hockey goaltenders were published in the 1970s (22, 23), to our knowledge no review has addressed the goaltender position's advancement and current founding. Numerous papers have investigated goaltenders as ice hockey players and less as a position specialist; with the current accumulated knowledge in the field, it is essential to visit the following question: What are the current guidelines and recommendations to improve physical condition and on-ice performance of goaltenders?

Stage 2: Identifying relevant studies (Eligibility criteria)

Inclusion and exclusion criteria were based on previous research papers and discussed by the authors scoping review in detail. This scoping review has been prepared to include all ice hockey studies that incorporate goaltenders within their group sample.

Inclusion criteria:

- Research articles were not limited by geographical location or settings of the study.
- Research articles were limited to English or French.
- All age, sexes and level of competition (i.e. Recreational, Varsity, or Professional) were included.
- Ice hockey studies that included goaltenders in their analysis.
- Outcome variables had to be health-related to maximize performance, rehabilitative interventions, psychological aspects specific to the position or physiologically based.
- Studies were published between1970 and February 2021.
- Qualitative Research was also included.

Exclusion criteria:

- Opinion works, magazine and newspaper articles.
- On-ice hockey studies that excluded goaltenders from their protocol and dataset.

Search Strategy

A search was made (February 1st, 2021) with the central database that included SportDiscuss, Scopus, WebofScience, PsychInfo and MEDLINE for published literature. Similar searching strategy was used in each database. Since the literature on ice hockey goaltenders is specific but broad, all relevant studies were reviewed. The search included "hockey" as the main keyword with term related to goaltender. The search on the five-database used hockey AND (goalie* OR goalkeeper* OR goaltender*). The search strategies were reviewed and consulted with a research librarian from the McGill University Life Sciences Library.

Stage 3: Study selection

Titles and abstracts were collated and investigated by the first author who screened full-text articles for eligibility. The first author shared the eligible sources for review by a second author. Full articles that were considered eligible via inclusion criteria were sourced. The first author then performed the independent investigation, referring via inclusion and exclusion criteria. If uncertainty and/or disagreement on a study's eligibility came up, a consensus was discussed with the third author for final decision. Authors were contacted for full texts when not available or for inclusive language (i.e.: French, English). Despite browsing via McGill

University library databases, connecting with authors and requesting text from the University's Central Interlibrary Loan Service, 15 were not able to be sourced and 7 were limited by foreign language. As outlined in Figure 1, 41 papers were reported as not relevant, while 6 were added through other sources since they were considered as relevant.

Stage 4: Charting the data

Data extraction were created by the first and second author. A sample of the first 5 studies were independently extracted from both authors and examined to assess the extraction strategy for consistency in answering scoping review's questions. The first author extracted majority of data, while the second author reviewed 10% of the extracted data for quality check. Information was input within a consistent analytical procedure for all the chosen research. Information was recorded as follow:

- Author(s)
- Year of publication
- Origin (Place of investigation)
- Aims/Purpose
- Study population and sample size
- Methods
- Research Design Type
- Data collected (i.e. Questionnaires, Heart rate)

- Outcomes and details related to results
- Key findings related to scoping review question

Stage 5: Collating, summarizing and reporting the results

Descriptive data and main findings are summarised and examined for critical analysis. Results are presented numerically and thematically based on qualitative and quantitative data analysis. A quantitative analysis was map and sum the data to display common themes, the period of publication and study methods. A thematic analysis was also described to present how the current research displays the scoping question within the literature. A consistent approach was taken for both qualitative and quantitative data. The standard approach was display to the primary characteristics, key concepts/evidence developed, and research gaps identified.

In this study we aim to:

A. Map the key concepts and findings on ice hockey goaltenders.

B. Summarise and organise the evidence in a practical approach for practitioners, exercise physiologists and coaches.

C. Report research gaps in the current literature on ice hockey goaltenders for further inquiry and future research priorities.

RESULTS

Descriptive analysis

Our initial search found 472 studies, after duplicates were manually excluded, 245 records remained. From the remained studies, 111 were identified to not meet inclusion criteria. From the 134 reports assessed for eligibility, 41 were found to be irrelevant ensuing to a full text review. These data are displayed in Figure 1. Six supplemental studies were added following searches, authors' discussion and references. The scoping review flow diagram is presented with search's details and selection process. In summary, 99 studies were included and identified as relevant to answer this scoping review's aims and foremost question 'What are the current guidelines to improve physical condition and on-ice performance of hockey goaltenders?

Included studies by year of publication

The growth in the number of studies since 1970 is plotted in Figure 2. This increase in the number of studies of both ice hockey and goaltenders' literature is associated with a growth in both study designs and research questions on the subject over the years.

Geography of included studies

Table 1 enumerates the geographic contribution of studies included in the scoping review.

Study design

Table 2 enumerates the type of studies included in the scoping review.

Theme of the study

The scoping review conceptualized included studies that merged into 6 main themes:

1. Position specificities and characteristics (N=22)
2. Reaction Time (N=8)
3. Injuries associated with ice hockey goaltenders (N=35)
4. Goaltenders' equipment (N=11)
5. Goaltenders' psychological aspects (N=13)
6. Youth development (N=5)

These themes were divided from theoretical deduction subsequent to the reading of the included studies. Additional studies were converged in a last group theme 'other' (N=5) to include studies of statistical analysis on goaltenders' performance and settings that were considered as insightful by the authors. Articles investigating injuries constitute the majority of included studies followed by articles investigating position specificities and characteristics. Figure 3 illustrated the scoping review's themes primary focus.

Table 1. Geography of included studies

Country	Number of studies	Percentage of studies
USA	43	43.43
Canada	40	40.41
Sweden	4	4.04
Switzerland	3	3.03
Czech Republic	2	2.02
Slovakia	2	2.02
Japan	1	1.01
Australia	1	1.01
Croatia	1	1.01
Germany	1	1.01
UK	1	1.01
Total	99	100

Table 2. Type of studies included

Type of study	Number of included studies
Cross-Sectional study	36 (35.64%)
Case-control study (Retrospective)	5 (4.95%)
Cohort study (Prospective)	28 (27.72%)
Case study	6 (5.94%)
Qualitative	14 (13.86%)
Other	10 (9.9%): 3 Descriptive epidemiology design, 3 Non systemic-Review, 2 Descriptive statistical design and 2 Conference proceeding (abstract)

THEMATIC SUMMARY – KEY CONCEPTS AND EVIDENCE AVAILABLE

Theme 1: Position specificities and characteristics

Movements patterns

Goaltenders perform constant technical movements, restraint useless actions and utilize proficiently one's protective equipment (24). The most frequent movements were crouching in their stance, moving laterally, dropping down in butterfly, and moving around the net to play the puck (9). The repetition of these movement patterns places a high demand on goaltenders' lower body joints (13). Goaltenders' stance places their hip in constant contraction by being flexed, slightly abducted and internally rotated while dropping down in the butterfly position also places further flexion, abduction and internal rotation on their hip muscles (25).

Defining Goaltender's Performance

The ability to react in uncertainties and chaotic plays using good technical abilities and anticipatory abilities of puck's actions determine the goaltender's performance (26). Although they can impact the game directly (10), they are often difficult to assess. Goaltenders' assessment of performance has been present via games played, wins, losses, shut-outs, goals-against average (GAA), and save percentage (SVP) (27). Simply looking at only one of these metrics has been suggested to underrepresent goaltender's performance (28). Both wins and quality starts have also been proposed as evaluation measures for ranking performance in goaltenders (29). However, both team's win and last year's performance have not been found to be significant indicator of goaltenders' evaluation at the NHL level. The SVP has been proposed to be the best predictor (30), and yet been critiqued of not representing the type of shots (28). Shot types and distributions may vary between games via dangerous angles, rush shots, number of rebounds and players' level of fatigue (28). Since a goalie can execute technical movements properly and still get scored on, a conceded goal is a statistical illustration of goaltenders' performance that does not necessarily represent the goaltenders' capacities or skill. (24, 31-35).

Physiological profiling and testing

Goaltenders' specific training has been described to be mainly focused on flexibility, reaction time, hand-eye coordination and on-ice skills (14). High levels of flexibility and mobility are required by successful goalies to maintain quality movements over large range of motion (36). Goaltenders were found to have better trunk flexibility (15, 37, 38), hamstrings flexibility (5, 36, 37) compared to the skating positions. Goaltenders are found to only have a slight elevation of lactate levels during playtime compared to resting values (15, 37). Since they highly rely on ATP-PC system and glycolysis when further time is spent in the defensive zone (37), both aerobic and anaerobic capacity should be trained to counter the effects of fatigue, prevent injuries, and maintain ideal psychological functioning (5, 14). When tested off the ice, goaltenders were also found to score significantly lower than skating positions for both the broad and vertical jumping (39). Analysis of NHL goaltenders' prospects found that they had significantly lower leg power, $\dot{V}O_2$ max, total lean mass, and vertical jumps compared to skating positions (14, 36). Upper body strength was also found to be lower in goaltenders (36, 38).

Hydration and Thermoregulation

Goaltenders are at risk of hypohydration (35, 40) and hyperthermia (15, 35). Heat loss is obstructed from their equipment which recommends constant fluid replacement (5). Being at risk of losing 2.4% of their body mass, mild dehydration has been suggested to increase core temperature, heart rate and perception of fatigue in goaltenders (5, 35). Perceptual concerns on hypohydration have been more issued during practice than game situations (35), suggesting more awareness of drinking fluid during game intervals. A carbohydrate-electrolyte solution has been recommended to reduce perceived fatigue and on-ice movement efficacy of goaltenders compared to water alone (35).

Cardiovascular system

Goaltenders' on-ice demand can cause the heart rate (HR) to rise to 200 bpm during practices and simulated scrimmages at a junior level (35, 41). Respectively the mean HR of old-timer goaltenders and junior prospects was monitored during scrimmages at 143 bpm (42) and 149 bpm, respectively (41). Scrambles around the net were found to result in the highest HR readings (43), while the lowest HR were reported when action was away of the defensive zone (42). Non-movement related factors have been found to increase HR and these include: emotions, static muscle contraction, and elevated core temperature (15). A strategy to reduce HR has been suggested through slower breathing patterns (44, 45), thus establishing breathing patterns during performance may help to lower elevated HR.

Theme 2: Reaction Time

Early focus and long duration of shot's release have been considered as successful performance for goaltenders faced with direct and deflected shots (34). Both stick and ice surface in front of the puck were found to be the areas where the eyes are most fixated (46), while peripheral information also offered kinematic information for reactions (32, 34). Effective reactive coordination is dictated with early perceptual information such as the nature of the shot (i.e., slapshot, wrist shot) (47), blade, pass options, stick and shooter's body (32, 34, 48). The horizontal plane was proposed to be more necessary than vertical cues (48), while wrist shots were easier to predict than slap shots since players present more information before the shot release (48). High-velocity shots can actually surpass human visual capacity (46). Thus, anticipation is required for appropriate coordination (26, 48). Anticipation has been proposed at an elite level, whereas only reactive behaviours seem to be achieved at a beginner's level for success (49). There are two information-processing approaches for reaction: predictive control and prospective control (32). While a predictive approach planned actions before the shot (anticipation), a prospective approach continuously analyzes the projectile until the interception point (32). Goaltenders were found to use a predictive approach when facing 10 m shots with five occlusion situations, while a prospective approach may have also been used (32). Despite the reliance ratio of these information-processing approach, a goaltender must train to locate the puck and sustain their focus on the shot's release for optimal performance (34).

Theme 3: Youth development

Relative age effect

The goaltenders' main skills may peak at different times: reaction time may peak early on while anticipation and positional play may develop as the athlete get older (50). During puberty, the relative age effect (RAE), which is the deviation of birth date distribution, has been claimed to impact talent recognition (51). RAE was initially confirmed in professional male goaltenders (52) and confirmed in recent studies (51, 53). 48 goaltenders were analyzed and RAE was presented in the best goaltenders of the groups while not being an influence in youth category (51). RAE was also proposed to not influence goaltenders from Swedish women's elite, junior elite, and youth female ice hockey (54). The distinct tactical and technical positional demands have been proposed to explain the stronger RAE in goaltenders (53). In youth sports, RAE requests inquiries in players' selection in which talent recognition should be based on technical and tactical skills rather than physical assets (55).

Pulling the goalie

Benching a goaltender result in missing a rotation or a scheduled start. Among young goaltenders benching has been associated with negative outcomes including: lack of learning, negative self-worth and damaged relationships (56). Young athletes rely on teammates and coaches for optimal emotional development in sports (57), and benching is often perceived as a punishment, as an athlete's self-worth may be impacted (56). Benching is a mental burden that goaltenders need to face and overcome (56). Communication of the decision's and reasonings between parents, coaches and youth goaltenders needs to be clarified (56) to present the experience as a learning opportunity.

Theme 4: Goaltenders' Psychological aspects

Distinctive mental approach

Elite goaltenders require a profound knowledge of the game (58) and must constantly evaluate and react to the sequence of events that takes place in game situations (59). The uniqueness of the position's demand forces the development of a distinct mental approach (60). Since their position restricts them to remain in their crest during playing time, goaltenders report lower levels of team identification and subjective in-group perceptions (60). One single mistake made by a goaltender in game can directly lead to a loss, thus they must withstand an increased sense of pressure (10). This attitude of self-blame has been related to delayed forgiveness by teammates (10). Negative perceptions from teammates can lead to fear of not performing well, self-blame and a sensation of guilt (10). Goaltender's fear has been related to anxiety and avoidance of the situation (41). Good performance via high SVP has been associated with experience, high arousal level, lower stress and practical emotional sharing abilities, while bad performance via lower SVP has been associated with higher stress, elevated physical tension and lower concentration ability (43, 61, 62). This perceived performance represented by goal outcomes may lead to perceived pressure by goaltenders (63). Strategies of adaptation to these physiological stressors and defining goaltender's motivation may help better conceptualize goaltender's potential and career longevity (41).

Coping strategies

Coping strategies from goaltenders' psychological and physiological demands may be hindered by stress and high cortisol levels (41). Goaltenders have been shown to use numerous forms of self-practice and organized mental skills such as: concentration, arousal control, breathing/centering, self-talk and imagery (58, 62, 64). Imagery can be used for technical improvements in their performance (58, 65) and help control one's emotions (62). Goaltenders benefit more from external visual imagery, as imagery associated with self-confidence and skill execution (58). Self-talk has also been mentioned as a positive tool to approach the game confidently and positively (62). Self-talk and focus towards improved performance have been associated with an increase in SVP (64). Concentration solely on the game while disregarding external distractions and thoughts is essential for goaltenders' success (62). These practices create confidence for goaltenders who then master their physical abilities to confront these constant threats (10). High confidence is essential for high performance and may be a perceptual trait (10, 58). Goaltenders depend more on their sole ability to perform despite their team and must build a strong sense of confidence (10). Positive social support from coaches and teammates interpreted by goaltenders can help them reduce stress-related health problems (10, 61). Specialized support is needed for goaltenders, and inadequate coaching may pose a challenge (10). Although there is an increased level of autonomy for the goaltender when creating their intervention, it can often lead to frustration and discouragement when limited specialized coaching is given (10).

Theme 5: Goaltenders' Equipment

Goaltender' Helmet

Goaltenders are vulnerable to concussion from three events: falls, collisions and puck impacts (66). Each event has its unique impact parameters characterized by distinct acceleration curves that produce different kinematic and brain responses (66, 67). Goaltenders' helmet were tested with high protective characteristics from both falls and puck impacts (68), yet offered inadequate protection during shoulder collisions' simulated events (69). Goaltenders' helmet material were measured with strong protective materials for puck impacts (68) but assessed more significant strains and impacts for both falling and collisions events (70). Modern goaltenders' helmet have been found to reduce concussions assessed by a reduction of impact from the puck (68) however, there remains a lack of regulated test protocols for adequate protective capabilities from the three events (67).

Goaltender's pads

Dropping velocities were found to be faster in pads when using a flex-tight pad compared to flex-wide and stiff-wide channel options (71). In addition to impact on-ice performance, goaltenders' pads options availability of size, stiffness and flexibility may influence injuries' incidence (25). Even with the invasive aspect of goaltenders' equipment, goaltenders' pad conditions and options availability were proposed to have an insignificant effect on hip internal rotation (25).

Theme 6: Injuries associated with ice hockey goaltenders

Prevalence of injuries

The prevalence of injuries has increased over time as the speed of play augmented (5). The proportion rate of injuries is significantly higher in goaltenders compared to skating positions (72) recognizing goaltenders as one of the most *at-risk* players on the ice (12). Male goaltenders were found to have a rate of injuries of 0.5/1000 players games and 0.72/1000 players games for female goaltenders (73). During the 2001-2007 NCAA seasons, 40 % of male and 46% of female goaltenders reported being injury after contact with a player (12). Goaltenders are vulnerable to contact related injuries since they focus their attention solely on the puck's location, making them unaware of other potential risks (12).

Lower body injuries

Hip-related injuries, particularly in the groin regions (74), have impacted goaltenders in the NHL, with 15.2% of the population being affected (72, 75). Hip and groin problems have been reported at higher rates in goaltenders compared to skating positions due to their positional demands (76). Although up-and-down movement patterns place a high load on the knee (77), goaltenders were found to be the position with the fewest ACL tears in both a ten season (78) and five season databases (79) at the NHL level. Since hip-related injuries may have long-lasting effects, current and previous hip-related injuries should be treated aggressively and early (76). Early hip-related injury identification tools may include the five-second squeeze test (5SST) (76). The 5SST identifies hip-related injuries (76), while assessing abduction and adduction strength (80). Adduction strength is vital for performance and injury prevention (80) when demonstrating 80% of the abductor strength (81). Goaltenders have reported continuing to play injured despite persistent groin, hip and overuse injuries (resulting in 83% of injuries) (80). Off-season in hockey may not be long enough to undertake strength training that would prevent reinjury of the hip (76, 82). The challenge is to develop training regimens and strength that would specifically target the groin and help recondition the player to peak performance and reduce injury incidence without jeopardizing one's performance when in season.

Femoroacetabular impingement

Goaltenders have the highest prevalence of cam-type deformity (83), lower lateral center edge angle and small acetabular coverage compared to skating positions (84). These conditions are common in goaltenders since they repetitively execute movements and sustain positionings that require hip end range of motion (83, 84). Although the etiology of femoroacetabular impingement (FAI) is still unclear, it is thought to be caused by skating biomechanics, early age exposure, style of play, and hip constant positioning; both alpha angle measurement and cam type deformity's location have been identified as good clinical signs in FAI identification (83, 85). Diagnose via symptoms, clinical signs and imaging findings (86), FAI can be treated by open or arthroscopic hip surgery. Arthroscopic hip surgery is presented with a faster return to play (87) and preoperative performance (88). Since muscles are mechanically affected by FAI (89), lower body muscles (i.e.: adductor longus, hamstrings, hip abductors, hip flexors) should be conditioned (90), despite surgery interventions, to prevent injuries and reinjuries. A systemic preventative approach would be to track hip load and restrain the number of butterflies allowed in practice at a young age (74, 80, 85, 90). The use of the butterfly is difficult to eliminate in modern hockey, and so the use of movements related to FAI's etiology may be unavoidable.

Since FAI may ultimately lead to further complications like osteoarthritis (87), and time loss due to hip injuries (84), early recognition and treatment of FAI in goaltenders is critical.

Concussions

Goaltenders are at lower risk of concussion compared to skating positions (91-93). Canadian amateur hockey league reported 379 concussions during the 1999-2000 season, and only 4-6% of these head injuries were experienced by goaltenders (91). The NCAA also reported a low prevalence of concussions for goaltenders in both men and women division, representing between 3% and 15% of all players (92). The prevalence of concussions may be due to the league rules disparity, speed of play, and style of play.

DISCUSSION

We aimed to display the current literature on ice hockey goaltenders and future research priorities. This is the first scoping review on ice hockey goaltenders. The available evidence displays numerous themes yet investigates the specifics of the positional characteristics of ice hockey goaltenders. The number of themes on the position identified from the literature suggests a high complexity to the position. This scoping review suggests early structure and involvement in goaltenders' development for career longevity, specific training programming for optimal performance and injury prevention. The most prominent themes were related to injuries caused by the positional demand with 35 scientific articles. Most studies reported the prevalence of injuries in goaltenders (Grant et al., 2014; Laprade et al., 2009; Kuzuhora et al., 2009; Mckay et al., 2014; Pinto et al., 1999; Rishiraj et al., 2009). Only recently, further studies investigated the magnitude and the burden of the problem between injuries and goaltenders (Mehta et al., 2019; Worner et al., 2020). In addition to display the prevalence of hip injuries, studies presented strategies to evaluate conditioning states while coping with the demand (Worner et al., 2020; Worner et al., 2020). They also proposed approaches for rehabilitative protocols, screening strategies and conditioning regimens (Mehta et al., 2019). The scientific literature sourcing the most prominent themes through injuries bring inquiry to the regularity of goaltender's training. A specific training must prepare the athletes for the positional demand. It is undeniable that goaltending place high stresses and loads on the lower body (Mehta et al., 2019), but that should not be a basis to get injured acutely in that region. The high prevalence of injuries, the low conditioning values evaluated (Bell et al., 2008; Burr et al., 2008; Vescovi et al., 2006), in addition to the scientific literature displaying studies related to injuries should be regard as a reminder to put more attention on goaltender's training specificities while not jeopardizing one's capacity. A training regimen for rehabilitative and conditioning purposes need to aim:

- On-ice practice performing edge control, crease work, and butterfly actions.
- Strengthening abductor muscles, hip flexor muscles, adductor muscles, core muscles, balance and sports specific movements.
- Optimizing or readjusting sports' related biomechanics to maintain level of ability during competitive calendar.
- Screening frequently hip's range of motion, especially at the start of competitive year and when injuries occurred, to prevent injuries, focus training regimen and fasten the recovery period.

The three most prominent themes of this scoping review consist of injuries (N=35), position characteristics (N=22) and psychological aspects of goaltenders (N=13). We can presume the scientific literature emphasize its effort to characterize the positional demand of goaltender while assessing its risk of performing. Even with numerous studies presenting goaltenders specificities, we can claim the inefficiency of the position to deal with their sport requirements. This inefficiency is shown with the high number of related studies on injuries, low testing values over time and portrayment of goaltenders' physiological capacity. Goaltenders are assessed with lower physiological capacity compared to skaters' position (Bell et al., 2008; Burr et al., 2008; Vescovi et al., 2006). Although the physical testings evaluated may not value goaltenders' positional requirements (Burr et al., 2008), yet it may also propose goaltenders are inadequately condition. The position has been presented with a high-risk factor for injuries with its biomechanical demand (Mehta et al., 2019). Yet, adequate training specificities must be investigated and presented to the goaltender's community for better conditioning strategies within sports organisations. We could assume the current literature to characterize goaltender's demand and requirement have inadequately present the knowledge concerning injuries prevention. More studies may be needed towards the specificity of the position prior to structuring the training regimens of the position. The demand performed must be cope with less compensation possible. It may be that most goaltenders are not able to deal with the demand while using low amount of compensation. This led to an increased risk of injuries as it has been presented in the literature being the most prominent themes of this scoping review.

The three other main themes are composed of goaltenders' equipment (N=11), Reaction time (N=8) and Youth development (N=5). Reaction time is a part of the training specificities for goaltenders as it involves hand eye coordination. Goaltenders may gain benefits from reaction time training. Panchuck, Vickers and Hopkins (2017) instruct to train goaltenders in locating the puck early and sustain a focus line of vision. Training reaction time may be accomplished by implementing exercises obstructing the line of vision and forcing goaltenders to work against external factors to make the save (Panchuk & Vickers, 2017). Reaction time is a training that can be develop both on and off the ice, adding to the numerous others specific training sessions they must structure for their development. This training arrangement may be advised by referred experts in the field of conditioning. An early arrangement to these trainings may establish early routine and habits assisting their long-term progression for that position specialist. Youth development was also a main theme identified in this scoping review. A healthy long-term development entail playing multiple sports during youth to reduce the risk of injuries since mature goaltenders are predominant of developing overuse injuries (Worner et al., 2020). This long-term skills development aligned with Brander et al. (2014) who proposed a peak development later in age for goaltenders compare to skaters as anticipation and positional play peak later in the case of the position specialist. A long-term developmental path and early structure may additionally be beneficial for the goaltenders when they are experiencing mental burden (Battaglia et al., 2018). An early preparation and conversation may support the youth goaltenders to perform as they cope with a unique mental demand. An early preparation set and referred by experts will not only support the goaltenders to play the sport mindlessly, but it will also prepare them to reach a higher level of performance by establishing early routine and habits. These routine and habits would favor the youth goaltenders to develop adequately as an athlete, lessen the risk of injuries, and manage properly the mental burden faced by the position.

Relevant research priorities identified – gaps

This scoping review has organized Table 3 research priorities and gaps in the existing literature on ice hockey goaltenders.

Strength and Limitations

This scoping review is a broader approach that aimed to map the numerous aspects and characteristics of goaltenders. The number of studies with the given investigation strategies did not ensure a complete screening by two authors. Yet, since the search terms are within a specific field of sports research, relevant studies on goaltenders have been identified and captured within the different databases. Given the vast themes on the subject and the few studies within those themes compare to other recent scoping reviews on sports (20, 94), this study includes themes as the literature presents them. A broad synthesis was investigated with the essential and available literature, yet it did not assess the quality of individual studies to investigate formal methodological assessment of the literature (20). Outlining cause and effect and revealing relationships are impossible when conducting a scoping review (94). Error in the interpretation may have occurred within studies that may have lacked control groups, had small sample size or context definition (20). When clarifying injury data, distinct interpretation strategies are used and should be accounted within their distinct context for a better critical understanding. Goaltending is a far more complex and specific position than the skating positions, even by being in the same sport. Identifying specificities and characteristics of goaltenders was attempted throughout this study by reporting evidence objectively (19). Despite the recognized limitations, the primary research question was addressed, and an outline of evidence was also established for coaches, physicians, policymakers, and other stakeholders in hockey.

CONCLUSION

The demand of ice hockey goaltenders is definite to be constantly challenging mentally and physiologically (10, 36). The high prevalence of injuries and the significant number of practices to master movement patterns and technical characteristics place the specialist in a performance equilibrium. Since insufficient preparation and lack of specific conditioning may lead to injuries by external factors and position demands (12, 13, 76); Specific trainings must be prepared for specific goaltenders' demands to improve performance and manage injuries. Indeed, off-ice training should be focused on strengthening and sustaining flexibility and mobility, general strength and power for on-ice movements proficiency and anaerobic and aerobic capacity to counter fatigue and maintain ideal body functioning. These off-ice training strategies should be organized to prepare the athlete for the on-ice demand. On-ice training should focus on movements proficiency, reaction time for early puck reading and general conditioning with goaltender's gear to cope with high core temperature. Specific athletic training is required for youth and older players to master this position. Interventions on psychological coping mechanisms should also be structured to manage the stress related to the position. Hence, the available evidence suggests early interventions involving mental and physical trainings to optimize goaltenders' performance and longevity of goaltenders' career. Although rehabilitative investigation and prevalence of injuries have numerously been researched, structure conditioning interventions and specific prehabilitative assessment should be built for future ice hockey goaltenders' inquiries. This review suggests that goaltender performance and injury prevention may be optimized through the interactive involvement of transdisciplinary teams, including: coaching staff, sports medicine, exercise science, sports psychology and athletic trainer.

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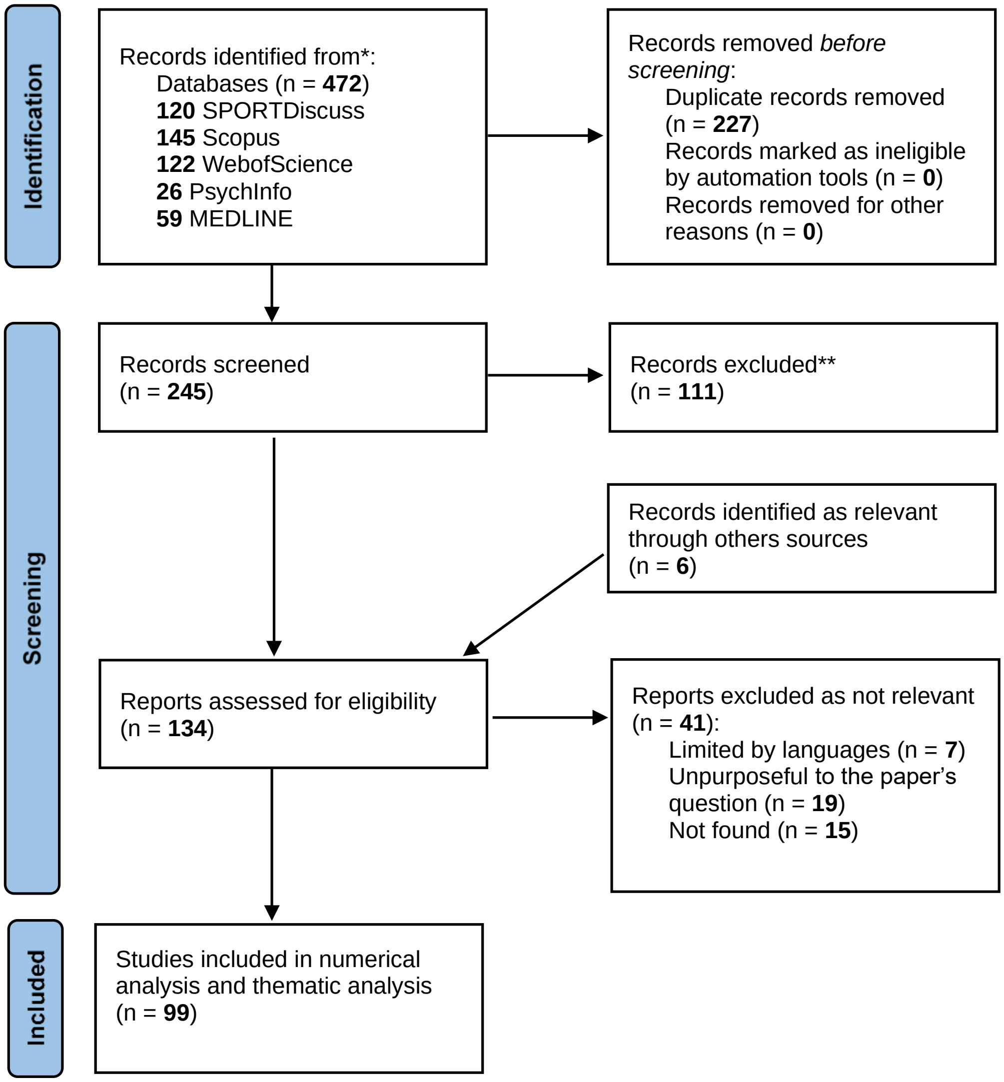
Figure 1. Scoping review flow diagram



Adapted From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Figure 2. Chronological increase of included studies

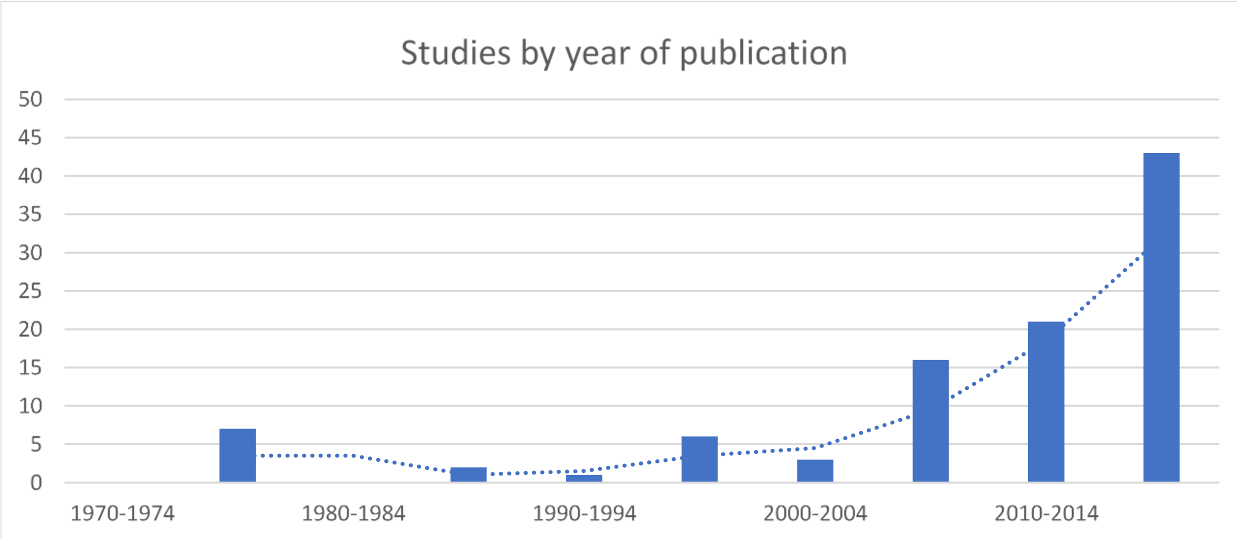


Figure 3. Scoping review's themes primary focus

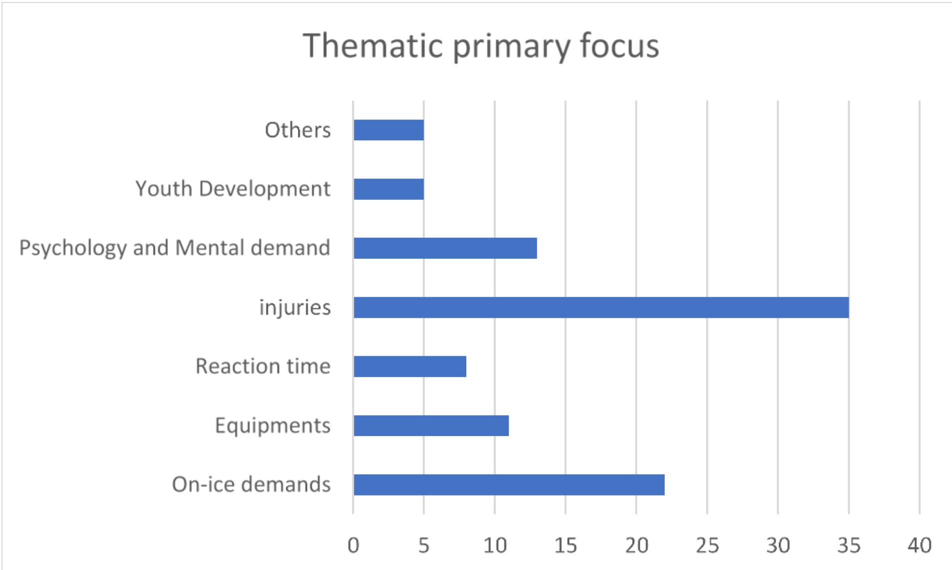


Table 3. Research priorities related to ice hockey goaltenders

Research priority relating to ice hockey goaltenders	Comment	Why required
Movement patterns	Goaltenders' movement patterns’ physiological and biomechanical demands may bring insightful details on the position's demands and potentially prevent overuse and chronic injuries.	Weight of evidence low
Physiological characteristics	Research assessing goaltenders' off-ice testing to identify the main physiological characteristics and build a reproducible on-ice protocol that monitors the on-ice demand.	Knowledge gap
Statistical analysis of performance	Since statistical norms of performance throughout the years change as the game also develops, finding better statistical analysis and multivariate performance data for goaltenders would establish an understanding of performance and conceptualize sport's evolution over time.	Knowledge gap
Reaction time	Research examining the learning outcomes and progression on both expert and novice with the modern trend of virtual reality training.	Weight of evidence low
Injury prevention	Research identifying the requirement of surgery interventions and provide specific timetable criteria. Reference values may also be needed to assess goaltenders' lower body strength and range of motion, specifically their abductors, adductors, quadriceps and hamstrings, to	Knowledge gap

Chapter 5 – Summary, Conclusion, Recommendations and Practical Applications

5.1 Summary

The initial purpose of this project was to characterize breathing patterns and heart rate responses adopted during the four patterns most used by goaltenders: T-push, butterflies, shuffles, and butterfly slides. Due to the Covid-19 pandemic, insufficient participants were available and therefore the initial study was not permitted to be performed. The thesis project was quickly changed to a scoping review on ice hockey goaltenders. The purpose of the scoping review was to map the current and available literature, summarize and organize the current evidence on the position, and report research gaps to inform the practice of ice hockey goaltenders.

A scoping review was established for this project to integrate various knowledgeable scientific findings on goaltenders and gain an accessible understanding of the position. A five-stage scoping review methodology was used to process the scoping review. The study also followed and completed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-Scoping Review (ScR) checklist to structure the style of the paper.

Data extraction was created by the first and second author. A sample of the first 5 studies were independently extracted from both authors and examined to assess the extraction strategy for consistency in answering scoping review's questions. The first author extracted the majority of data, while the second author reviewed 10% of the extracted data for quality check. Information was input within a consistent analytical procedure for all the chosen research.

The scoping review conceptualized included studies that merged into 6 main themes: position specificities and characteristics (N=22), reaction Time (N=8), injuries associated with ice hockey goaltenders (N=35), goaltenders' equipment (N=11), goaltenders' psychological aspects (N=13), youth development (N=5). These themes were divided from theoretical deduction subsequent to the reading of the included studies. Additional studies were converged in a last group theme 'others' (N=5) to include studies of statistical analysis on goaltenders' performance and settings that were considered as insightful. Articles investigating injuries constitute most included studies followed by articles investigating position specificities and characteristics.

We aimed to display the current literature on ice hockey goaltenders and future research priorities. This is the first scoping review on ice hockey goaltenders. The available evidence investigates the specifics of the positional characteristics of ice hockey goaltenders. The number of themes on the position identified from the literature suggests a high complexity to the position that is necessary for understanding. This scoping review suggests early structure and involvement in goaltenders' development for career longevity. In addition, the need for position-specific training programming for optimal performance and injury prevention became prioritize. Goaltending is a far more complex and specific position than the skating positions. Identifying specificities and characteristics of goaltenders was attempted throughout this study by reporting evidence objectively.

5.2 Conclusion

Within the delimitations and limitations of this project, the following conclusions are:

1) Goaltenders must base their off-ice training on the specifics of their demands to perform at the highest level, remain healthy and increase career longevity. Off-ice training should increase substantial flexibility and mobility, lower body strength to build power and

movements speed, both anaerobic and aerobic capacities need to be optimized to counter fatigue, maintain ideal body functioning and optimize hand-eye coordination.

2) On-ice training should focus on movements patterns, proficiency to move skillfully, reaction time to read the puck's location at the earliest, and conditioning while wearing goaltenders' equipment to get acclimatize to higher core temperatures and mild hydration.
3) Goaltenders on-ice primary skills may peak late and at different times. Therefore, sampling that entail youth to practice various type of sports and physical activities may be the conventional path for this position. The athlete should have the chance to experience and practice diverse sports during adolescence, allowing the acquisition of skillsets from other sports, and then specialize in early adulthood.
4) The distinct psychological stresses imposed on goaltenders require the development of a distinct mental approach to the game. Coping strategies such as concentration, arousal control, breathing/centering, self-talk and imagery must be implemented to help reduce psychological stresses caused by negative self-talk, teammates, the hockey environment, and in some cases the media.
5) Injuries associated with goaltenders are diverse and common. Goaltenders are most likely to be affected by lower body injuries. The early assessment intervention should be structured for goaltenders to avoid reinjury and time loss in rehabilitation. Structure strength and a sport specific mobility training regimen should be structured early in developing goaltenders to allow effective habits and behaviours to promote success and longevity.

5.3 Recommendations

Based on the findings of this study, the following recommendations are warranted:

1. Further studies should be conducted to assess the physiological characteristics of elite goaltenders which may result in reproducible on-ice protocols that monitors goaltenders' on-ice demand.
2. Statistical analysis of performance throughout the years changes as the game also develops; finding better complex statistical methodology that incorporate multivariate performance data for goaltenders will help to establish an understanding of performance and conceptualize the sport's evolution over time.
3. Future studies should attempt to identify reference values to assess goaltenders' lower body strength and range of motion, specifically their abductors, adductors, quadriceps and hamstrings, to help identify the origin of the injury. This may lead to a reduction in the rate of reinjury and the prevention of injuries in the future.
4. Research investigating the long-term effects of leg pad wear on a goaltender's body and performance represents a research priority, as well.

Practical Applications

Ice hockey goaltending is both challenging mentally and physiologically. Goaltenders need to master complex, specialized movement patterns and technical characteristics in order to thrive. In addition, high levels of aerobic and anaerobic training are required for youth and older players to master this position. Yet, insufficient preparation and lack of sport-specific conditioning may lead to injuries by external factors and position demands. This study summarizes and maps essential insights on the available evidence of the position. The six main themes displayed in this scoping review emphasize the high prevalence of injuries carried by goaltenders while presenting the unique positional characteristics and specificities. We can assume the demand is higher and distinct for goaltenders compare to skating positions and yet inadequately described for the current goaltenders' demand. This inadequacy is shown with continuous reports of goaltenders' impaired functions suggesting their poor conditioning compared to skater positions by scoring poorer in physical testing. Early structure and conditioning related to goaltenders' development may lessen the risk of injuries faced by the demand. At this time, modern equipment's can efficiently lower the risk of injuries from external factors, likewise a conditioning established for youth goaltenders may benefit from a proper training regimen establishing early habits to lessen the prevalence of injuries while enhancing goaltenders' development. The future practice of goaltenders must reduce the risk of injuries, enhance a spectrum of support related to mental burden dealt specifically by goaltenders and establish systematic training regimen aligned with the specific skills needed for the demand. This project may provide valuable information to improve performance and training for goaltenders by bringing insightful and condensed scientific findings on the position. Since the position is complex with multiple topics that need to enclose its abilities and characteristics, numerous multi-disciplinary team-members should be involved in helping goaltenders achieve peak performance. This review suggests that goaltender performance and injury prevention may be optimized through transdisciplinary teams' interactive involvement, including coaching staff, sports medicine, exercise science, sports psychology, and athletic training specialists.

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