Ice training workload relation to the game workload in ice hockey

Patrick Kåla

Haaga-Helia University of Applied Sciences

Research-based Thesis

2024

Bachelor of Degree programme in sports coaching and management

Abstract

Author
Patrick Kåla

Degree
Bachelor of Degree programme in sports coaching and management

Thesis title
Ice training workload relation to the game workload in ice hockey

Number of pages and appendix pages
52

The purpose of this study is to provide insights into the amount of load and intensity of forwards and defensemen in the ice practices in relation to game amount of load and intensity. The data for the study was collected from a professional team playing in the Finnish main league, Liiga, during the 2022-2023 regular season.

The data collection utilized Firstbeat Sport Sensors (Firstbeat Technologies) to gather information on the amount and intensity of load in the ice practices and games. Data was collected from ice practices (GD-2, GD-1, GD-0) and games (GD). The key variables in this study are the internal load variable TRIMP, the external load variable movement load, and the intensity of the internal load variable TRIMP/min and intensity of the external load variable movement intensity. Differences in the variables were compared using paired samples t-tests. The data collection for this study was conducted as part of Marko Haverinen's dissertation research.

Both forwards and defensemen, on average, experienced higher internal load (TRIMP) and external load (movement load) in the games compared to ice practices. When examining the intensity of the load, forwards had a higher average TRIMP/min only in the ice practice conducted two days before the game (1.09 ± 0.49 vs. 1.07 ± 0.29). On the other hand, forwards had a higher average movement intensity in all ice practice sessions compared to games. Similarly, defensemen had a higher average TRIMP/min only in the ice practice conducted two days before the game (1.22 ± 0.42 vs. 0.96 ± 0.26). The other intensity variable, movement intensity, had a higher average in all ice practice sessions compared to games for defensemen.

The study demonstrated that the load and intensity in the ice practices decreases as the game approaches, regardless of player position. When examining both internal and external load, games were significantly more demanding than ice practices for both forwards and defensemen. Regarding the intensity of the load variable, movement intensity was higher during ice practices than games for both player positions. This could be due to the fact that during games, data is collected for the entire duration of the match, including time spent on the player bench and during intermissions. The results aid coaches in considering the planning of ice training to achieve game-like loads for both player positions throughout the team's training week.

Keywords
Ice hockey, team sports, external load, internal load

Table of contents

1 Introduction

Ice hockey is a high-intensity and challenging team sport that requires players to possess sufficient technical, tactical, physical, and psychological attributes. The challenging nature of the sport is because it is played on an ice surface with players wearing skates, and the game involves using a puck as the playing object, which is carried, passed, and shot with sticks. Due to the ice, players are required to have a significant amount of skill, especially in technical abilities, particularly in the present era when the game has become increasingly faster in recent years, and situations unfold rapidly during the match.

In terms of physical requirements, ice hockey demands players to have sufficient attributes in areas such as strength, speed, endurance, and mobility. Professional male ice hockey players skate approximately 4-5 km during a game with almost 50 % as high-intensity skating, resulting in an average on-ice heart rate (HR) of ~85 % maximum HR (HRmax), confirming both substantial aerobic and anaerobic components (Lignell, Fransson, Krustrup, & Mohr 2018; Montgomery, 1988; Stanula, Roczniok, Maszczyk, Pietraszewski & Zajac 2016; Vigh-Larsen & al., 2020a).

Neeld, K., Peterson, B., Dietz, C., Cappaert, T. & Alvar, B. (2021) studied the external load in the United States collegiate hockey NCAA Division 1 where one ice hockey team wore Catapult S5 units for all on-ice activities for two consecutive seasons. With Catapult S5 units they measure seven workload variables (player load, skating load, explosive efforts, high skate load, player load min^{1}, skating load min^{1}, and average stride force lb^{1}) were used to quantify training and match workload characteristics. This study points out that in collegiate men's ice hockey, matches required significantly higher values in measures of intensity and volume compared to training. Specifically, matches resulted in significantly higher player load, total skating load, explosive efforts, high force strides, and average stride force lb^{1}. On the other hand, training led to higher player load min^{1} and skating load min^{1}. This indicates that the workload characteristics differ between training and matches in collegiate men's ice hockey, with matches demanding higher intensity and volume, but lower work rate compared to training. (Neeld & al. 2021.)

Allard, P., Martinez, R., Deguire, S. & Tremblay, J. (2022) studied the match load and intensity across player positions and match periods, the distribution of pre-game training load and intensity over training days before a match by player position, and the cumulative weekly training load over at 2017-2018 AHL Season. These 50 players were part of the Laval Rocket AHL team during that period. A total of 173 team practice sessions were collected, representing 3,226 individual on-ice training and match sessions throughout the season. On-ice training sessions were categorized into either regular practices or morning skates, the latter being practices that occur on the morning of a match. Subjects were categorized into 1 of 3 on-ice positional groups representing defenseman, center, and winger; goaltenders were excluded. Study monitored external load in every training session and match over the season using portable inertial measurement units housing a triaxial accelerometer, gyroscope, and magnetometer. The results indicated that defensemen have lower intensity during matches compared to forwards, while the load is similar across positions. (Allard & al. 2022.)

On the other hand, Reinikainen conducted a study in 2021 on the seasonal variation of skating load by playing position in the top-tier Finnish ice hockey league (Liiga) during the 2019-2020 season. The research material consisted of 146 ice hockey players' shift-specific skating data from 372 regular-season matches played during the 2019-2020 season in the top tier of Finnish ice hockey. The data for the study was collected using the Wisehockey sports analytics system developed by Bitwise Oy. The study employed repeated measurements on three player subgroups categorized by playing position (centers, wingers, defensemen). Skating load assessments were conducted using the Wisehockey analytics system, which is based on a local positioning system provided by Bitwise Corporation. The skating variables examined included: accelerations and decelerations exceeding 0.5-second thresholds per shift, accelerations and decelerations within different threshold ranges per shift, time on ice per shift and per match, relative and absolute time spent in various velocity ranges per shift, skating distance per shift and per match, skating distance within different velocity ranges per shift, maximum and mean velocities per shift, and the number of visits exceeding 1-second intervals at different velocity limits per shift. The study found that forwards performed more high-intensity and maximal decelerations, skated at higher speed ranges, and had greater average and maximum skating speeds compared to defensemen. On the other hand, defensemen spent more time at lower-intensity speed ranges compared to forwards. Based on the results of the study, changes in skating load throughout the season do not appear to be position dependent. (Reinikainen 2021.)

From previous studies, it can be concluded that in ice hockey, the workload of the game differs from that of ice practice, as the game imposes a greater workload than ice practice. Additionally, it has been found that defenders accumulate more low-intensity load than forwards, while forwards are found to engage in more high-intensity work than defenders, despite defenders having higher game times than forwards. Forwards even find it challenging to replicate the workload of a game in training, as their absolute game workload intensity has been found to be up to 15% higher than that of defenders. (Allard & al. 2022; Neeld & al. 2021; Reinikainen 2021.)

The objective of this study is to examine the differences in workload between ice practices and games for different playing positions within a professional ice hockey team. Consequently, the research question focuses on how the workload of ice practices differs in relation to the game specifically for forwards and defensemen. Generally, there is still limited research in this area on the hockey side. This was precisely one reason why I became interested in this topic, as I can also learn a lot about ice hockey workload through this study.

This study examines the amount of load and intensity of professional ice hockey players on a professional ice hockey team in the ice practices and games throughout the regular season of the 2022-2023 season. The team competed in the Finnish Ice Hockey League, which is the top-tier ice hockey league in Finland. The team and players are anonymized in this study. Players were categorized into forwards and defensemen. Goaltenders were not monitored in this study. The data collected for the study was conducted as part of Marko Haverinen's dissertation research. For this study, data was collected using Firstbeat Sports sensors from Firstbeat Technologies Oy. Players of the participating team worn sensors during both ice practices and games. The data focused on amount of load (TRIMP and movement load) and intensity of load (TRIMP/min and movement intensity).

Data for the study were collected from games and ice practices (GD = game, GD-0 = game day morning skate, GD-1 = day before the game ice practice, and GD-2 = two days before the game ice practice). Due to the team's intense game schedule, there were very few ice practices three and four days before the game, as well as ice practice on the day after the game or two days after the game, leading to the exclusion of the results of these specific ice practices in this study.

2 Ice hockey as a sport

As a sport ice hockey is a fast-paced, team sport built on skill, speed, discipline, and teamwork. It is a game that requires quick thinking and fast reactions along with the development of many special skills such as skating, passing, puck handling and shooting. (IIHF 2010.) It is metabolically versatile and sets big demands on both the cardiovascular system and the nervous-muscular system. It is an interval-type, physiologically varied game that includes a lot of starts, stops, changes of direction, contacts and maximum accelerations as the player reacts to game situations. The length of intensity and recovery times between the intervals vary randomly depending on the game situations. (Laaksonen & Vähälummukka 2016, 567-568.)

Ice hockey evolved approximately 150 years ago and has grown significantly in the last century. The International Ice Hockey Federation was founded on May 15, 1908, in Paris, France. Currently, the headquarters of the International Ice Hockey Federation is in Zurich, Switzerland. The president of the organization is Luc Tardif, a Canadian French national, who has been in office since 2021. (IIHF 2023.)

The first men's ice hockey Olympic Games were played in 1920 in Antwerp, and ten years later, Austria, Germany, and France hosted the inaugural World Championships. In the initial two decades, Canada dominated both the World Championships and the Olympic Games in ice hockey, winning eleven out of thirteen events. The interruption caused by the Second World War slightly disrupted Canada's dominance, and in the following sixteen tournaments, five different countries managed to secure victory at least once. In 1963, the Soviet Union began its triumphant march, securing twenty championships over the next nearly thirty years. (IIHF 2023.)

Nowadays IIHF annually organizes the Ice Hockey World Championships for men, U20, U18, as well as women and girls U18. Since the 1990s, the winner of the men's World Championships has changed almost every year, with only the Czech Republic managing to win three consecutive golds at the turn of the millennium. Finland reached the podium for the first time in 1992, securing a silver after losing the final to Sweden. Three years later, the medal was upgraded to gold, also against Sweden. Overall, since 1992, Finland has won a total of 16 World Championship medals (including the silver in 1992), with four of them being gold. During these years, Canada, Russia, Sweden, and the Czech Republic have also won multiple world championships. Canada leads the medal table for men's ice hockey World Championships with a total of 53 medals, including 28 golds. In the Olympic Games, Canada has won gold three times, Sweden, and Russia twice, and Finland and the Czech Republic once each. In addition to the Olympic gold in 2022, Finland has won four Olympic bronzes and one silver. In the Women's World Championships, Canada dominated the

1990s, and the United States has been dominant in the 2000s so far. Finland ranks third in the medal table with 13 bronzes and a silver from the 2019 tournament. Finland's women reaching the final was historic, as before that, the final had always featured Canada and the USA. (IIHF 2023.)

Games under jurisdiction of the International Ice Hockey Federation (IIHF) must be played on an ice surface surrounded by a rink and must adhere to the dimensions prescribed by the IIHF and these rules. The official size of the rink must be 60 m long and 26 m to 30 m wide. The corners must be rounded in the arc of a circle with a radius of 7.0 m to 8.50 m. Any deviations from these dimensions for any IIHF competition require IIHF approval. (IIHF 2022, 31.) Comparing to North America hockey rinks are narrower (26 m) and longer (61 m) than in Europe.

The world's premier ice hockey league is unequivocally the NHL (National Hockey League), where most the world's best players compete. The NHL consists of 32 teams, with seven based in Canada and the rest in the United States. In recent years, the second-strongest ice hockey league in the world has been considered the Russian KHL (Kontinental Hockey League), which has featured teams from various countries. However, due to the ongoing military conflict initiated by Russia in Ukraine in 2022, the KHL has lost several top players from other countries and teams that participated from abroad, leading to a decline in the league's overall quality. Other prominent and highly competitive leagues in Europe currently include Sweden's SHL (Swedish Hockey League), Finland's Liiga, and Switzerland's NL (National League). Additionally, the Czech Extraliga and Germany's DEL (Deutsche Eishockey Liga) have elevated their standards in recent years, posing challenges to the top European leagues. (Eliteprospects 2023.)

In addition to the leagues in various European countries, the Champions Hockey League (CHL) was established in 2013. For the 2023-2024 season, 24 European teams from different leagues participate in addition to their domestic league games (Russian teams do not participate in the CHL). The format of the CHL for the 2023-2024 season has been changed from the previous format. Now The six Shareholder Leagues will take 18 places in the new format, equally split to three representatives each. Teams will qualify in their domestic leagues on sporting merits according to the following criteria:

- National Champions
- Regular season winners
- Regular season runners-up
- Regular season third place

The reigning CHL Champions are automatically qualified for the next CHL season, which grants an extra qualification place to their league. The minimum of participating countries is set at 11 and therefore five Wild Card teams from Challenger Leagues will be part of the CHL. Figure 1 visualize the team selection format of the 2023-2024 CHL season. The allocation of Wild Cards is subject to Board approval for each season and will be decided at a later stage. (CHL 2023.)

Figure 1. Team selection format for the 2023-2024 season of the Champions Hockey League (CHL) (CHL 2023)

On the professional level ice hockey season usually lasts approximately 7 to 9 months depending on country and the league. Especially, in the highest league in the Finland (Liiga) regular season consist of 60 games for each team (Liiga 2023).

Before the start of the regular season, teams play a varying number of preseason matches, aiming to develop the team's performance and gather additional data about their own game system and players. After the conclusion of the regular season, the teams that have performed the best in the league standings participate in the playoffs, where it is determined which team becomes the champion of that season.

Compared to NHL regular season consists of 82 games. Depending on the team’s success, the postseason could add up to an additional 28 games. Including a 4-week preseason preparatory period, NHL players are competing from mid-September up through the first week of June. (Neeld 2018.) For example, normal week during regular season in NHL, teams might have 3-4 matches, 2-3 recovery sessions, 2-3 on-ice training, and 1-2 off-ice conditioning sessions or in Europe top teams might have 1-2 matches, 1-2 recovery sessions, 4-5 on-ice training, and 2-3 off-ice conditioning sessions per week during the in-season period (Brocherie, Girard & Millet 2018). As we can see, the season itself sets tough physical demands on those playing hockey at the top-level.

A Game is contested between two teams which play under the direction of on-ice and off-ice officials. A Team consists of 22 players. No more than 20 skaters and two goaltenders shall be permitted. (IIHF 2022, 39.) Of these, only five (excluding the goalkeeper) will be actively participating at one time, and constant in-game substitutions are allowed. This means that ice hockey is played at a very high intensity. (Nightingale 2014.)

Skaters are normally divided into three playing positions which are wingers, centers, and defenders. If the lineup is fully there are normally four units which usually include center, two wingers and two defenders. According to Summanen & Westerlund (2001, 25) at the beginning of ice hockey, the respective roles of the players were simple: the defensemen defended, and the forwards attacked. As the game has evolved, the tasks of the positional roles have converged, and tasks are increasingly assigned according to a game plan. At the junior level is very useful to play different playing positions and learn as much as possible for different playing positions. It is very common that coaches teach game to players using four different playing situations roles which Summanen & Westerlund (2001, 25) point out in their book, and which are presented in the figure 2.

Rapid decision-making and co-operation is possible because of different playing situation roles:

1. *In offensive role with the puck.*
2. *In offensive role without the puck.*
3. *In defensive role covering the opponent with the puck.*
4. *In defensive role covering the opponent without the puck.*

Figure 2. Four playing situations roles. (Summanen & Westerlund 2001, 25)

A typical ice hockey game consists of three 20-min stop time periods, interspersed by 15-min rest intervals (Brocherie & al. 2018). Team with most goals wins. If the teams are tied after three periods a sudden-death overtime period takes place the first team to score wins. If no team scores during the overtime period, a shootout takes place. (IIHF Worlds 2023 4.5.2016, 1:40-2:05 min.) Above-mentioned formula for overtime period is usually in regular season, but in the playoffs, overtime length is 20 minutes and consist of 15 min intermission and it will be played until either team scores.

3 Physical demands of ice hockey

Ice hockey is an intermittent team sport characterized by high intensity, short duration bursts of maximal power, whilst also requiring players to have well rounded physical capabilities, including speed, strength, and endurance, alongside the ability to execute a variety of skilled maneuvers (Douglas & Nightingale 2018, 157). It is characteristic of team sports, also for ice hockey, that fatigue develops progressively during match, which can be seen in the amount of movement and a decrease in the intensity towards the end of the match (Lignell & al. 2018; Vigh-Larsen & al. 2020).

3.1 The physiological load of the game

A typical game lasts for 60 minutes, and apart from the goalkeeper, players take it in turns to perform on the ice. These shifts vary due to several factors, but they generally last between 30 and 90 seconds, are interspersed with between 2 and 5 minutes of recovery, and number around 15 to 20 each game**.** Within the shifts themselves, work is not completed at a constant speed or intensity. Players are afforded brief recovery periods during whistle stops for infractions, and when performing at low or moderate intensities, such as gliding or standing still. (Douglas & Nightingale 2018, 157.)

With large interindividual variation due to the ability to substitute players freely, as well as the occurrence of powerplay situations/penalty killing which may alter the players' block rotations and total playing time. For instance, key players may occasionally spend over 30 minutes on the ice, especially if games extend into overtime (Vigh-Larsen & Mohr 2022.)

Lignell, Fransson, Krustrup & Mohr (2018, 9) reported in their study that elite ice hockey players skate 2300-6800 meters during a game and players spent time on ice 10-25 min. In same study Lignell & al. (2018) found that players performed 19 ± 1 (8–32) sprints during the game with an average length of 26 ± 1 (17–34) m and peak and average sprint speed were 28.6 ± 0.1 km/h and 25.5 ± 0.1 km/h. In figure 3 Brocherie & al. (2018) present shift characteristics per period during the official international ice hockey game.

TABLE 2. Shift characteristics per period during the official international ice hockey game.

Period	Effective playing time (min)	Number of shifts	Effective playing time per shift (s)	Stoppage time (s)	Bench time (min)
1	5.7±0.8	7.4±1.0	46.81±4.76	39.24±4.07	3.7±0.5
2	5.0±1.1	7.2±1.8	41.76±5.06	42.41±3.00	4.4±1.5
3	5.4±1.8	7.7±2.4	43.47±6.71	43.48±4.21	5.5±2.0*
Mean	5.4±1.2	7.4±1.8	44.01±5.71	41.71±4.07	4.5±1.6
Total	16.1±3.6	22.3±4.9	132.04±10.45	125.13±22.64	13.5±3.8

Mean ± SD. * ($P<0.05$), significantly different from period 1.

Figure 3. Shift characteristics per period during the official international ice hockey game. (Brocherie & al. 2018, 263)

Neeld (2018, 2) point out that in ice hockey players move approximately 50 % of the time in high intensity during the shift. Brocherie & al. (2018) have found in their study that elite ice hockey players spent ~18 % of the effective playing time on high intensity skating activities (>18 km/h). In figure 4 Brocherie & al. (2018) present time-motion patterns from the international hockey game.

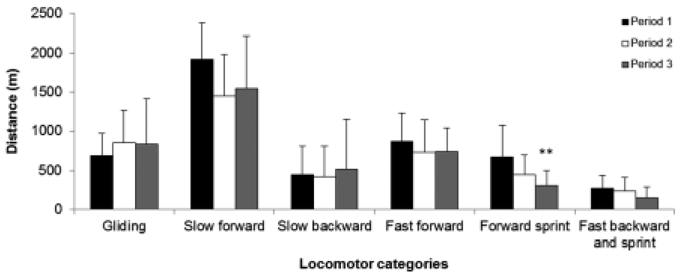

FIG. 1. Distance covered in low- (gliding, slow forward and backward skating) and high-intensity (fast forward, sprinting, and fast backward skating and sprinting) locomotor categories during the first, second and third periods of the official international ice hockey game.
** Significantly different ($P<0.01$) from period 1.

Figure 4. Ice hockey time-motion patterns. (Brocherie & al. 2018, 265)

Douglas & Kennedy (2019) tracked movement in-match in IIHF U20 junior's world championship tournament 2018-2019 and found that defenders move significantly more in slow and moderate speed ranges in matches compared to forwards, while forwards move more in very fast speed ranges and sprint speeds. In figure 5 Douglas & Kennedy (2019) present average game distance during an ice hockey game in meters what they found in their study from IIHF U20 junior's world championship tournament.

Position	Total distance	Very slow distance (1.0–10.9 km·h^{-1})	Slow speed distance (11.0–13.9 km·h^{-1})	Moderate speed distance (14.0–16.9 km·h^{-1})	Fast speed distance (17.0–20.9 km·h^{-1})	Very fast speed distance (21.0–24 km·h^{-1})	Sprint distance (>24 km·h^{-1})
Defense	4,002.4 ± 786.7	666.9 ± 162.3†	569.3 ± 136.8†	696.5 ± 151.4†	1,022.7 ± 209.7	600.4 ± 143.3*	446.5 ± 176.3*
Forward	3,681.2 ± 1,058.2	391.5 ± 143.4*	357.1 ± 121.4*	501.6 ± 170.8*	935.4 ± 296.3	740.5 ± 250.7†	755.1 ± 230.8†

*Distance covered in meters at different speed thresholds from 5 world class international ice hockey game (defense $n = 7$, forward $n = 13$). Data are mean ± *SD*.
†$p \leq 0.05$.

Figure 5. Average game distance (m) during an ice hockey game in meters. (Douglas & Kennedy. 2019, 641)

In addition, from Jackson, Snydmiller, Game & Gervais (2016) study we can found that playing positions also differ in terms of the ratio of work and recovery when the work-recovery ratio during the 5vs5 has been found to be for defenders about 1:2 and for forwards about 1:1.3, while the work-recovery ratio during the whole match has been found to be about 1:3.1 for defenders and about 1:4.1 for forwards.

3.2 Energy production in hockey

The main energy production system in a hockey is the anaerobic energy production system. Immediate energy stores adenosine triphosphate (ATP) and phosphocreatine (PCr) are mainly used for accelerations, bodychecks, and shooting. ATP and PCr are sufficient for about 10 seconds. (Laaksonen & Vähälummukka 2016, 569.) When ATP and PCr stores are used after 10 seconds and player continues with intensive way, the energy production system will switch to anaerobic glycolsis (Laaksonen & Vähälummukka 2016, 569). These are the main energy sources in ice hockey, and their utilization occurs concurrently with the determination of energy needs for each source. Summanen & Westerlund (2001, 19) point out that anaerobic glycolysis is the main source of energy for a single shift, accounting for 60 – 70 percent of the entire energy production of a work period. Figure 6 illustrates the proportion of the energy production system's contribution to the total energy demand at maximal exercise duration.

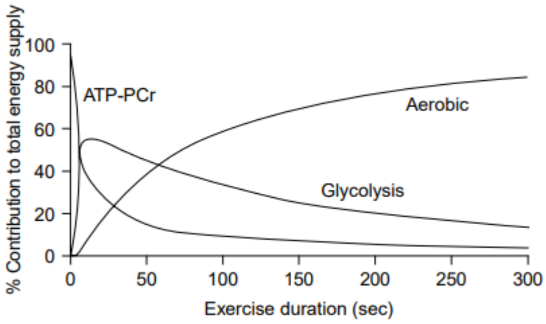

Figure 6. Relative energy system contribution to the total energy supply for any given duration of maximal exercise (Adapted Gastin 2001, 30)

In ice hockey players must have a well-developed aerobic capacity which they need to recovery on gliding phase during the shift and on the bench between shifts. As we know, hockey game consists of two 15 minutes intermission where players can recovery and prepare to next period. Gharbi, Dardouri, Haj-Sassi, Chamari & Souissi (2015) states in their study that a high aerobic capacity can, for example, speed up short-term recovery between high-powered sprints and thus help resist fatigue.

Ice hockey game contains several high-powered performances, the benefits of a well-developed aerobic capacity for ice hockey player. Also, well-developed aerobic capacity is necessary for players to recovery during season between practices and games. (Laaksonen & Vähälummukka 2016, 569.)

Hockey game events are usually quite long event almost four hours include warm-ups and game. In professional level some teams have morning practice session before game which also increase demand of the aerobic system. Wisløff, Helgerud & Hoff (1998) found that the players of the team that won the Norwegian football league had a significantly higher aerobic capacity compared to the players of the team that finished last in the league.

The stress of the game has also been studied by monitoring heart rates. The heart rate provides an overall picture of stress level where aerobic energy production occurs. In ice hockey game, the average working heart rates of the players vary between 170 – 174 bpm (beats per minute) and during the resting period, heart rates can drop to 110 – 120 bpm. (Summanen & Westerlund 2001, 20.)

According to Nightingale (2014) In-game studies have shown the working heart rate of athletes to be at around 90% of maximum heart rate, with athletes spending around 20% of total game time at this intensity. It is very interesting to note that Summanen & Westerlund (2001, 20) point out that defensemen working heart rates are on average 10 – 15 bpm less than those for forwards. In figure 7 Jackson, Snydmiller, Game & Gervais (2016) present heart rate measurements from female university ice hockey. In their study Jackson & al. (2016) found that in female hockey, players spent 84% of time at a low to moderate intensity which involves intermittent high intensity activities that vary according to player position and game play situation. Whereas Stanula, Roczniok, Maszczyk, Pietraszewski & Zajac (2014) Tracked HRs (Heart rates) from Polish under-20 (U20) national team and found maximum HRs of 194.7 ± 8.3 and 190.7 ± 6.2 bpm, and average HRs of 159.1 ± 7.1 and 150.7 ± 7.8 bpm. So, we can notice that peak HRs from men hockey players are a bit higher than female hockey players.

HR Measurement	Defense	Forwards	All Players
Peak Shift HR	184 ± 12[a]	180 ± 7[a]	182 ± 10[a]
Mean Shift HR	176 ± 11[a]	173 ± 7[a]	174 ± 9[a]
Low HR Between Shifts	129 ± 14	132 ± 10	131 ± 12
Mean HR Between Shifts	148 ± 14	148 ± 9	148 ± 11
INT 1 Low HR	103 ± 7	99 ± 8[b]	101 ± 8
INT 1 Mean HR	116 ± 9	112 ± 7[b]	114 ± 8
INT 2 Low HR	101 ± 9	108 ± 10	105 ± 10
INT 2 Mean HR	117 ± 10	123 ± 8	121 ± 9

a = significantly different from all recovery heart rates during shifts and during intermissions.
b = significantly different from peak and mean shift HR and the second intermission HR.

Figure 7. Mean (±SD) heart rate measures for all players during female ice hockey games (Jackson & al. 2016, 49)

Maximal oxygen uptake is considered the best performance indicator for several endurance-type performances. It indicates the power of the respiratory and circulatory organs and the muscles' energy usage. (Summanen & Westerlund 2001, 16.)

The measurement results of oxygen uptake capacity tests performed with a bicycle ergometer and a treadmill show that the average oxygen uptake capacity of ice hockey players varies between 52 and 58 ml/kg/min (Montgomery, 1988). According to Summanen & Westerlund (2001, 16) 60 ml/kg/min can be considered a good and sufficient figure for an ice hockey player. Ferland & al. (2021) point out in their study that minimal relative V̇O2max requirement to play North American hockey at the elite level should be 55.9 ± 5,2 ml/kg in sport-specific maximal oxygen test.

In hockey, performance is high-powered, thus, excess formation of lactic acid should be avoided. As such, the anaerobic threshold is a good performance indicator for an ice hockey player because the higher the anaerobic threshold, the more likely a player will be able to maintain a high intensity and skill performance during a game. An ice hockey player's anaerobic threshold levels vary between 70 – 80 % of the maximal oxygen uptake. (Summanen & Westerlund 2001, 8-16.)

Lactic acid concentrations vary between 3 – 14 mmol/l depending on the individual and the playing position in ice hockey. In the 1993 Swedish national ice hockey team played against Canada and Finland were measured the lactic acid concentrations ranged on average between 5 – 7 mmol/l. (Summanen & Westerlund 2001, 20.)

Noonan (2010) examined blood lactate values from Division 1 level ice hockey players and found that their blood lactate values ranged from 4.4 to 13.7 mmol/l, with a mean value of 8.15 (+2.72) mmol/l. Montgomery (1988) points out that because players can rest between shifts and game consist of two intermissions, the lactate concentrations repeatedly fall, which increases the power of the next performance.

Vigh-Larsen & al. (2019) found in their study that, the performance of hockey players at a higher league level was significantly better in the Yo-Yo IR1 test and, in addition, their load was less in the submaximal Yo-Yo test compared to players at a lower league level. It is important that in team sports players have reach sufficient level in the aerobic fitness which doesn´t restrict their physical performance during the match. This same thing was noted by Haugen, Hopkins, Breitschädel, Paulsen & Solberg (2021) in their longitudinal study, where only a subtle connection was observed between endurance of hockey players and their performance during the match.

3.3 Strength and power

According to Neeld (2018) ice hockey requires significant rotation through the thoracic and cervical spine, as well as glenohumeral range of motion in all planes. This helps support the high-velocity rotations associated with shooting, as well as widen the space around the body through which a player can accept and handle the puck.

Strength is main significant factor which separate professional players from amateurs. To prevent injuries players must have sufficient muscle mass and strength levels which covers bones and tendons from especially contacts. In hockey, particular emphasis is placed on the control and strength of the gluteal, abdominal, back, and oblique muscles. Also, the importance of the muscles of the hip and core is essential in situations that require balance, such as shooting and bodychecks. Players must have taken care of middle body muscles balance to prevent injuries because often groin and back injuries background are weaknesses of hip and middle body muscles. In ice hockey lower body strength effects to skating, agility, bodychecks, and accelerations. On the other hand, upper body strength impacts bodychecks, shooting, and puck handling. The upper body strength and lower body power are also beneficial for a player in battling situations. (Laaksonen & Vähälummukka 2016, 569.)

Forward skating is the most common in ice hockey and the stride directed to posterolateral plane, using the hip extensors and abductors. Hip and knee flexors and extensors co-contract to maintain stability and balance when weight is shifted to the glide leg in forward skating. (Nightingale 2014.)

Backward skating is second common in hockey, and it requires a combination of hip extension, adduction, and external rotation, along with knee extension. The glide leg also requires the co-contraction of hip and knee flexors and extensors to maintain balance. (Manners 2004, 16-17.)

According to Jackson & al. (2016, 47-48) Players spent the most time skating forward direction in the game and defenders skate backward more frequently and longer than forwards during all game play situations. In table 1 Neeld (2018) point out that the skating pattern has significantly longer ground-contact times and slower stride rates than running which has important implications for exercise selection.

Table 1. Ground-contact time and stride rates in forward and cross-over skating. (Adapt Neeld 2018, 2)

Skating pattern	Contact time (s)	Stride rate (strides/s)
Forward	0.33	1.64
Cross-over (outside leg)	0.37	1.55
Cross-over (inside leg)	0.33	1.67

3.4 Speed and agility

Ice hockey requires speed and agility from players. Speed is one of the most important characteristics of hockey. Speed is needed in all aspects of the game, both defending and attacking, in breakaways and battling of the puck. Agility and quick reaction ability are needed in different game situations, and in them excellent speed characteristics are needed to maintain and accelerate the pace. In addition, combining skating technique and speed is important and challenging. There are a lot of changes of directions and short accelerations in hockey game. That is why the speed and power of the first skating strides are the most important of the speed characteristics. (Laaksonen & Vähälummukka 2016, 569-571.)

Because skating skill and speed are key qualities in ice hockey, they are also significant factors when scouting player characteristics and making player selections. Ice hockey players' movement speed is usually tested by running or skating (Tiikkaja 2002). The specific speed of ice hockey is much more than just the absolute speed. That's why in hockey the emphasis is on speed with the skill. According to the definition of speed with the skill, in addition to speed characteristics, skill is also needed, and actions must be appropriate (Hakkarainen 2015, 239).

3.5 Anthropometry

The physical demands of ice hockey have increased over the years also because the size of the players has increased for example, in figure 8, Montgomery (2006) shows that the average height of the players of the Montreal Canadiens NHL team has grown considerably over the hundred years.

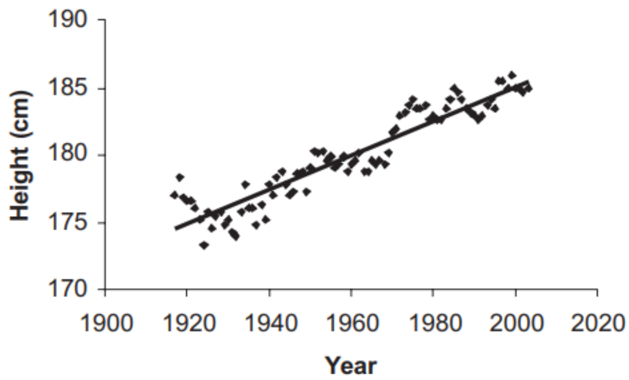

Figure 8. Height (cm) for the Montreal Canadiens hockey team from 1917 to 2003. (Montgomery, 2006, 182)

Chiarlitti, Delisle-Houde, Reid, Kennedy & Andersen (2018) made study from body composition of 37 male ice hockey player (years 21-26) from an elite Canadian collegiate hockey program where they found that Defensemen were heavier (88.10 ± 6.16 kg) and slightly taller (181.27 ± 6.44 cm) compared with forwards (86.48 ± 6.55 kg and 180.43 ± 5.32 cm). Also, Chiarlitti & al. (2018) point out in their study that the lack of significance in anthropometric and body composition variables was not surprising because the physical demands of each position (all players must be able to skate, shoot, and pass) are not at all that different. The table 2 below presents the measurements of different studies on the anthropometric characteristics of ice hockey players because nowadays there is still a large dispersion in these characteristics, so it is difficult to define only a certain kind of ice hockey player.

Table 2. Height, weight, and fat percentage in ice hockey players in different studies

Source	Serie	Height (cm)	Weight (kg)	Fat %
Tiikkaja (2002)	SM-liiga (n = 18)	182,0 ± 5,5	D: 89,6 ± 6,6 F: 84,5 ± 7,4	14,2 ± 2,8
Gustavsson (2002)	NHL (n = 5)	188,1	95,9	12,9
Villemejane (2009)	SM-liiga (n = 9)	183,3 ± 4,9	86,1 ± 5,1	
Kutáč & Sigmund (2015)	KHL Forwards (n = 19)	182,97 ± 5,61	89,70 ± 5,28	12,51 ± 3,10
Kutáč & Sigmund (2015)	KHL Defensemen (n = 11)	185,72 ± 3,57	92,52 ± 4,01	11,88 ± 2,49
Vigh-Larsen (2019)	Metal ligaen (n = 164)	182,3 ± 5,2	85,7 ± 8,1	15,1 ± 4,0
Korte (2020)	Liiga & U20-SM serie	182,2 ± 6,5 (n = 115)	84,9 ± 8,3 (n = 115)	14,3 ± 2,3 (n = 89)

4 Monitoring training load

Training load refers to a variable that is adjusted to achieve the desired training-induced adaptations in the athlete (Impellizzeri, Marcora & Coutts 2019). In other words, athlete performance development takes place through loading the athlete (Haverinen & Leppänen 2021). Foster, Rodriguez-Marroyo & De Koning (2017) describe that training monitoring is about keeping track of what athletes accomplish in training, for the purpose of improving the interaction between coach and athlete. Halson (2014) reminds that monitoring the training load of an athlete is important to minimize the risk of non-functional overreaching (fatigue lasting weeks to months), injury, and illness. In figure 9 Impellizzeri & al. (2019, 2) present theoretical framework of the training process when we want to obtain specific performance adaptations to athlete.

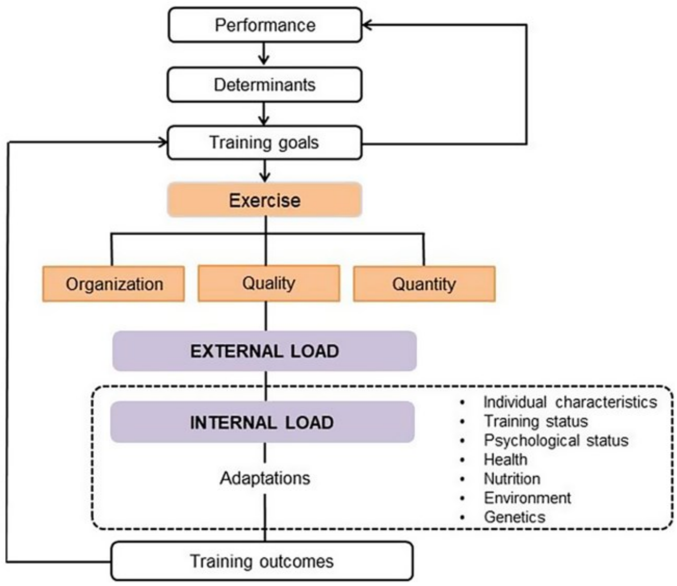

Figure 9. Theoretical framework of the training process. (Impellizzeri & al. 2019, 2)

When, monitoring training load, the load units can be thought of as either external or internal. Traditionally, external load has been the foundation of most monitoring systems. External load is defined as the work completed by the athlete, measured independently of his or her internal characteristics. While external load is important in understanding work completed and capabilities and capacities of the athlete, the internal load, or the relative physiological and psychological stress imposed is also critical in determining the training load and subsequent adaptation. (Halson, 2014.)

4.1 Internal load

Internal load refers to the physiological stress on the athlete during training, which is what largely determines the adaption to the training program (McGuican 2017, 70). Measures such as heart rate, blood lactate, oxygen consumption, and ratings of perceived exertion (RPE) psychological inventories, training impulse (TRIMP), are commonly used to assess internal load (Bourdon & al. 2017. S2-161-163). In table 3 Bourdon & al. (2017) present common variables to monitoring internal load.

Training Impulse (TRIMP) is a metric used to describe the exertion or load of a sports performance (Davidson 2021). The original TRIMP calculation was developed by Dr. Eric Banister in 1991. TRIMP considers the intensity (calculated by the heart rate reserve method) and the duration of exercise (measured in minutes). It is a way to quantify training load and stress placed on an athlete/player and is represented by a single number. (Firstbeat.)

It is also important to highlight that heart rate is a valid measure of internal load for endurance training but not for resistance training. Moreover, even within the same context, a single load measure may not have the same level of validity (eg, heart rate is a less valid indicator of internal load in short duration, intermittent high-intensity efforts compared with long distance or interval training). (Impellizzeri & al. 2019.)

For example, Polar, a manufacturer of heart rate monitoring devices, highlights that wrist-worn heart rate monitors and optical heart rate measurement from the arm may not provide accurate results in sports where hands move vigorously or muscles and tendons near the wrist stretch. Additionally, heart rate monitors may have limited ability to measure through dark or heavily tattooed skin. It is also common for users to wear the heart rate monitor too loosely or tightly. Polar emphasizes that a chest-worn heart rate monitor is the most accurate and reliable among these mentioned devices. (Polar.)

During short, very high-intensity sprint interval sessions whereby the total training load may be very small, despite the high effort and tissue stress. For example, a track running session consisting of 2 × 400 m at maximal effort, with full recovery between repetitions would likely register a very small training load derived from most metrics. (Renfree, A., Casadob, A & McLaren, S. 2021.)

TRIMP/min describes the pace at which the exertion or load of training is distributed over a specific time. TRIMP/min enables the mapping of an athlete's internal strain during the performance and allows for the comparison of the exertion between different performance instances. (Davidson 2021.)

In addition, to the internal workload measurement methods mentioned earlier, Halson (2014) highlights various other utilized approaches such as different subjective measures of perceived exertion and recovery, including sRPE (Session Rating of Perceived Exertion), POMS (Profile of Mood States), REST-Q (Recovery-Stress Questionnaire), and TQR (Total Recovery Scale).

Because the internal training load determines the training outcome, Impellizzeri & al. (2019) recommend that this can be used as primary measure when monitoring athletes. This is because the internal load experienced from a specific external load may vary depending on specific contextual factors either between or within athletes. For example, specific modifiable and nonmodifiable factors such as training status, nutrition, health, psychological status, and genetics may result in individual athletes experiencing a different internal load (and individual differences in adaptive processes) when provided same external load (Impellizzeri & al. 2019).

Table 3. Commonly used variables for internal load monitoring (Adapt Bourdon & al. 2017)

METHOD	COST	EASE OF USE	VALID	RELIABLE	VARIABLES
RPE	L	H	M-H	M-H	AU
sRPE	L	H	M-H	M-H	AU
TRIMP	L-M	M	M-H	M-H	AU
Wellness questionnaires*	L	M-H	M	M-H	Ratings, checklists AU scale measures
Psychological inventories	L-M	M-H	M-H	M-H	Ratings, checklists AU scale measures
Heart-rate indicates	L-M	H	H	M-H	HR, time in zones, HRV, HRR etc.
Oxygen uptake	H	L	H	H	VO2, metabolic equivalents
Blood lactate	M	M	H	H	Concentrations
Biochemical/hermatological assessments	M-H	L	H	M-H	Concentrations, volumes

Abbreviations: L, low; M, medium; H, high; AU, arbitrary units.
*Measures of training response

4.2 External load

External load measures are commonly used for quantifying training in aerobic endurance sports and team sports. The increasing use of wearable technologies has allowed for more systematic and detailed information on the external load measures such as distance covered and athlete speed. (McGuican 2017, 70.)

External training loads are objective measures of the work performed by the athlete during training or competition and are assessed independently of internal workloads. Common measures of external load include power output, speed, acceleration, time–motion analysis, global positioning system (GPS) parameters, and accelerometer-derived parameters. (Bourdon & al. 2017, 161.) In table 4 Bourdon & al. (2017) present common variables to monitoring external load.

Table 4. Commonly used variables for external load monitoring (Adapt Bourdon & al. 2017)

METHOD	**COST**	**EASE OF USE**	**VALID**	**RELIABLE**	**VARIABLES**
Time	L	H	H	H	Units of time
Training frequency	L	H	H	H	Session count
Distance	L	H	H	H	Units of distance
Movement repetition counts	L	M-H	H	M-H	Activity counts
Power output	M-H	L-M	H	H	W/kg, W
Training mode	L	H	H	H	Weight training, run, cycle, swim, row, etc
Speed	L-M	M-H	H	H	m/s. m/min, km/h
Acceleration	L-M	L	H	H	m/s2
Functional neuromuscular tests	L-M	M	M-H	H	CMJ and drop-jump measures
Acute: chronic-workload ratio	L-M	M	M-H	M-H	Size of acute training load relative to chronic load
GPS Measures	M	M	M-H	M	Velocity, distance, acceleration, time in zones, location

METHOD	COST	EASE OF USE	VALID	RELIABLE	VARIABLES
Time-motion analysis video (nonautomated)	M-H	L	M-H	M	velocity, location, acceleration
Accelerometry	M	L-M	M-H	M	x-y-z g forces
Player load	M	M	M	M	Single variable in AU (time dependent)

Abbreviations a: L, low; M, medium; H, high; AU, arbitrary units.

As a measure of external load, one can consider absolute values such as total distance, distance covered at different speed zones, as well as the quantities of accelerations, collisions, and decelerations. On the other hand, as measures of the intensity of external load, metrics include distance covered per minute (average speed), distance covered at different speed zones per minute, the number of accelerations, decelerations, and changes of direction per minute, as well as collisions per minute. (McLaren & al. 2018; Lovell & al. 2013.)

The outcome of the training process is determined by the internal load, which in turn is determined by the external load. Movement load deals with the external load. To achieve a certain internal load, external load is required, so to obtain this information, movement load is a useful tool. In other words, movement load adds context to internal load. At a practical level, it provides more insight into why a certain internal load has occurred. For example, in a soccer match, a player may have a higher TRIMP in the second half compared to the first. The initial conclusion you might reach is that they have fatigued as the game progressed. However, it may be that they moved more in the second half, perhaps because they were behind and had to chase the game. With movement load, we now gain an understanding of whether our player was tired and less efficient or simply moved more. (Stark.)

The player load (PL) is a commonly used training load variable in ice hockey which is formed, for example, from the sum of vectors derived from accelerometer data. The important gliding component combined with high-intensity intermittent skating, frequent body contacts, and multiple player substitutions raises doubts on the utility of PL to measure external load (EL) in-ice hockey. (Allard, Martinez & Tremblay 2022.)

Allard & al. (2022) recommend that external load in ice hockey would probably be better represented by the number and amplitude of skating strides, accelerations, changes in direction, collisions, and various key actions. Monitoring workload involves a wide range of tools and metrics. However, it's essential not to overcomplicate the process. There isn't a single metric that perfectly captures overall workload. It's recommended to use methods tailored to measure internal and external loads specific to each sport. (Haverinen & Leppänen 2021.) For example, in sports such as basketball, volleyball, and netball practitioners can use inertial sensor technology to count jumps during practices and matches to monitoring training load (McCuigan 2017, 191).

According to Harper, Carling & Kielyn (2019) various collisions, accelerations, decelerations, and changes of direction are a significant part of the external load in team sports, which can be measured using GPS and accelerometer sensors today. Vanrenterghem, Nedergaard, Robinson & Drust (2017) point out that in running-based team sports, GPS-based measurement has been shown to be a reliable method. Vanrenterghem & al. (2017) remind that has been noted that the more accelerations there are in the sport, the lower the accuracy is with the GPS method. In strength training, an external load can be used for example, by counting the kilos lifted, by counting the total number of repetitions in each movement and multiplying this by the load used in the repetitions (Impellizzeri & al. 2019).

Movement load quantifies the load of a session and adds context to internal load. In practical terms it gives more insight into why a particular internal load has occurred (Stark). For example, in an ice hockey game, a player may have a higher TRIMP in the third period compared to the first. The first conclusion might reach is that they have fatigued over the course of the game. However, it may be that they moved more in the third period perhaps because of being behind and having to chase the game. It is worth keeping in mind here that there can be quite a bit of variation between players as everyone moves slightly differently and will therefore accumulate movement load at different rates. Similarly, the typical movement load values seen in ice hockey are lower than sports like soccer or basketball because skating causes less oscillation within the accelerometer than running based activities. (Firstbeat.)

4.3 Monitoring training load in team sports

Monitoring in team sports is often perceived to be more challenging due to the diverse range of training activities (e.g., general conditioning, resistance training, interval training and skill-based conditioning) commonly employed. Further, the assessment of skilled performance and ‘cognitive load’ or fatigue that influences decision making is important for team sport performance and poses many challenges for accurate assessment. When monitoring team sport athletes, some of the most useful measures involve physiological changes, assessment of movement patterns and indicators of skills, with these measures being as sport specific as possible. (Halson 2014.)

In addition, McGuigan (2017, 190-191) note that the primary obstacle in monitoring athletes in team sports lies in the sheer volume of participants. In team sport settings, there may be as many as 30 to 50 athletes engaging in training or practice simultaneously. The substantial number of athletes escalates the expenses associated with monitoring tools, and the time constraints faced by practitioners pose an additional hurdle in the development of monitoring systems. This complexity renders large-scale monitoring challenging, prompting practitioners to frequently opt for straightforward yet efficient methods.

Halson (2014) point out that difficulties when assessing team sport competition performance include the influence of team tactics (including those of the opposing team), environmental conditions, team cohesion, home or away competition and travel. Thorpe & Drust (2017, 2-28) emphasize that since there is no single monitoring tool that can provide a complete understanding of a team sport athlete, practitioners should employ a diverse range of monitoring methods. This allows them to create a customized toolkit suited to the specific needs of the target group.

The focus should be put to manage the training load, reduce the injuries and illness, and optimize the performance of the team sport athletes. The monitoring methods needs to be familiarized and explained well to the athletes, so the athletes will approve the idea. This helps with compliance to the observing and improves the quality of the monitoring data. (McGuigan 2017, 200-201.) In addition, Thorpe & al. (2017, 2-28) Recommend that future tools should prioritize being non-invasive, easy to administer, swift in application, and should minimize any additional load on the athlete.

In team sports environments, an athlete's individual training load can be assessed through a training diary, which includes sections for recording the duration and content of each session, along with the Rating of Perceived Exertion (RPE) (McGuigan 2017, 190). Wellness questionnaires are employed to gauge overall well-being, quality of sleep, muscle soreness, fatigue, and stress. This insight allows for adjustments in the subsequent training session based on the results (McGuigan 2017, 197). The utilization of global positioning systems (GPS) and accelerometry devices for monitoring is widespread in high-performance sports. These tools have proven to be reliable and hold potential as field-based instruments for athlete monitoring (McGuigan 2017, 152). Wearable technologies represent a growing trend in exercise and sport science (McGuigan 2017, 136). These technologies are designed to offer continuous feedback during activities, and certain activity monitors have been explored for monitoring sleep in athletes. Ideally, wearable sensors should be user-friendly, compact, lightweight, and cost-effective (McGuigan 2017, 154-155). Additional prevalent monitoring practices in team sports include the use of biochemical and hormonal markers, performance tests, movement screening, and neuromuscular assessments (McGuigan 2017, 138).

5 Research implementation

5.1 Research objectives

The purpose of this study is to compare internal and external amount of load and intensity of load in the ice practice with the amount of load and intensity of load in the game for forwards and defensemen. The variable representing internal load amount is TRIMP, and the variable representing external load amount is movement load. The variables representing load intensity are TRIMP/min and movement intensity. The research questions are thus:

How does the amount of load and intensity of load in the ice practice differ compared to the amount and intensity of load in the game for forwards?

How does the amount of load and intensity of load in the ice practice differ compared to the amount and intensity of load in the game for defensemen?

5.2 Hypotheses

Based on the literature review and research questions the following hypotheses were formulated for the study:

H0: There is no difference in the internal and external load variables TRIMP and movement load between forwards ice practice and game load.
H1: The internal and external load variables TRIMP and movement load in the forwards ice practice differ from the game load.

H0: There is no difference in the internal and external load variables TRIMP and movement load between defensemen ice practice and game load.
H1: The internal and external load variables TRIMP and movement load in the forwards ice practice differ from the game load.

H0: There is no difference in the intensity of external and internal load variables TRIMP/min and movement intensity between forwards ice practice and game load intensity.
H1: The internal and external load variables TRIMP/min and movement intensity in the forwards ice practice differ from the game load intensity.

H0: There is no difference in the intensity of external and internal load variables TRIMP/min and movement intensity between defensemen ice practice and game load intensity.

H1: The internal and external load variables TRIMP/min and movement intensity in the defensemen ice practice differ from the game load intensity.

5.3 Subjects

The data collected for the study was conducted as part of Marko Haverinen's dissertation research and the data was collected from professional ice hockey players from one professional team which participated in the top-tier Finnish ice hockey league Liiga in season 2022-2023. The data consist of the entire regular season, consisting of 60 games, starting from mid-September, and concluding in mid-March. The data on practices has been collected from the ice sessions accumulated during the regular season. In this study, players were categorized into forwards and defensemen. Players average age was 25 years. The average weight was 84,7 kg, and the average height was 181,3 cm. The workload of goaltenders were not monitored in this study.

5.4 Methods and measurements

The load-related data used in the study was collected using Firstbeat Sports sensors during both regular-season games and ice training sessions that takes place during the regular season. In figure 10 the image showcases the Firstbeat Sports sensor. In this study players have been categorized into forwards and defensemen, and their data has been anonymized during the analysis. Using Firstbeat sports sensors, various variables related to load were collected in the study, including EPOC (ml/kg), EPOC Peak (ml/kg), Time under heart rate zones, TRIMP, TRIMP/min, Movement load, Average movement intensity, Average HR (bpm), Average %HRmax (%), Peak HR (bpm), and Peak %HRmax (%).

Figure 10. Firstbeat Sport sensor (Firstbeat)

The key variables in this study are the amount of load and the intensity of the load. Internal training load is examined using TRIMP, which represents the amount of load on the cardiopulmonary system. In figure 11 have presented how TRIMP is calculated in Firstbeat Sports. In figure 13 have presented the reference values for TRIMP and TRIMP/min provided by Firstbeat.

$$TRIMP = T\ x \left[\frac{(HR_{ex} - HR_{rest})}{(HR_{max} - HR_{rest})}\right] x\ 0.64e^{1.92\left[\frac{(HR_{ex} - HR_{rest})}{(HR_{max} - HR_{rest})}\right]}$$

Where:

T	duration of the workout
HRex	heart rate during workout
HRrest	resting heart rate
HRmax	maximal heart rate
e	~ 2,718

Figure 11. How TRIMP is calculated in Firstbeat Sports (Firstbeat)

External training load is assessed using movement load, which represents the amount of load on the neuromuscular system. The calculation is based on analyzing the measurement data from the three-dimensional accelerometer inside the heart rate sensor (measurement frequency 50 Hz). The sensor detects and aggregates all the movements occurring in the athlete's three movement planes. In figure 14 present the reference values for movement load provided by Firstbeat. (Firstbeat.)

Firstbeat has not published an official validation study on the reliability or repeatability of the variable. However, Nicolella, Torres-Ronda, Saylor & Schelling (2018) found in their study that the repeatability of the player load variable used by Catapult OptimEye S5 devices was reliable. This player load variable is based on the same calculation as Firstbeat's movement load calculation. Figure 12 illustrates how the Catapult player load variable is calculated.

$$\text{PlayerLoad}^{\text{™}} = \sqrt{\frac{\left(a_{y(t)} - a_{y(t-1)}\right)^2 + \left(a_{x(t)} - a_{x(t-1)}\right)^2 + \left(a_{z(t)} - a_{z(t-1)}\right)^2}{100}},$$

Figure 12. How Catapult player load is calculated a_y is forward (anterior-posterior) acceleration, a_x is sideways (medial-lateral) acceleration, and a_z is vertical acceleration (Nicolella & al. 2018)

The variables for load intensity in this study are TRIMP/min which describes the intensity of the load on the cardiopulmonary system. TRIMP/min is obtained by dividing TRIMP by the total duration of the exercise or game. The second variable representing the intensity of the load is movement intensity, which describes the intensity of the load on the neuromuscular system. Movement intensity is obtained by dividing movement load by the total duration of the exercise or game.

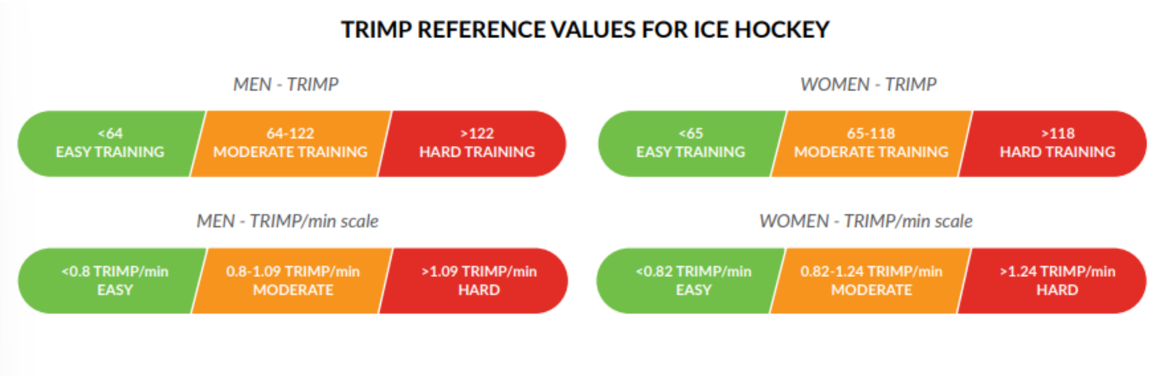

Figure 13. Reference TRIMP and TRIMP/min values for ice hockey from Firstbeat (Firstbeat)

Movement Intensity
Men Women

Training Effect Level	Movement Load Range	Movement Intensity Range
Easy (1.5 - 2.5)	60 - 120	0.8 - 1.2
Moderate (2.5 - 3.5)	89 - 164	0.9 - 1.2
Hard (3.5 - 5)	128 - 221	1.0 - 1.3

Movement Load
Men Women

Training Effect Level	Movement Load Range	Movement Intensity Range
Easy (1.5 - 2.5)	45 - 82	0.6 - 0.9
Moderate (2.5 - 3.5)	66 - 108	0.7 - 1.0
Hard (3.5 - 5)	92 - 158	0.8 - 1.1

Figure 14. Reference values to movement load and movement intensity range from firstbeat (Firstbeat)

In the study, ice practices recorded during the regular season were categorized as follows:

- GD = game
- GD-0 = morning practice on game day
- GD-1 = ice practice one day before the game
- GD-2 = ice practice two days before the game
- GD-3 = ice practice three days before the game
- GD-4 = ice practice four days before the game
- GD+1 = ice practice one day after the game
- GD+2 = ice practice two days after the game

In the Finnish Ice Hockey League, teams have a very intense game schedule during the regular season. There were significantly fewer practices recorded for GD-3, GD-4, GD+1, and GD+2 compared to other categories of practices. The results of these practices were excluded from the analysis because statistical methods could not have been feasibly implemented.

Additionally, not all players on the team consistently used sensors in games or practices, leading to data collection spanning the entire regular season to ensure an adequate amount. Furthermore, measurements with 10% or more measurement error have been removed from the data used in the study Below are the recording quantities from Firstbeat Sports sensors for the games and ice practices included in the study:

- GD = game (n = 88)
- GD-0 = morning practice on game day (n = 175)
- GD-1 = ice practice one day before the game (n = 488)
- GD-2 = ice practice two days before the game (n = 110)

In Table 5, the duration of ice practices (GD-2, GD-1, and GD-0) and games is presented separately for defensemen and forwards in the format (hh:mm:ss). "n" describes the number of recordings.

Table 5. The duration of ice practices (GD-2, GD-1, and GD-0) and games separately for forwards and defensemen

	GD-2 (hh:mm:ss)	**GD-1 (hh:mm:ss)**	**GD-0 (hh:mm:ss)**	**GD (hh:mm:ss)**
Defensemen	Mean: 0:57:16 Min: 0:45:34 Max: 1:09:26 SD: 0:07:11 *n = 37*	Mean: 1:01:40 Min: 0:20:37 Max: 1:30:16 SD: 0:18:02 *n = 175*	Mean: 0:32:45 Min: 0:15:32 Max: 0:44:51 SD: 0:10:16 *n = 73*	Mean: 2:34:43 Min: 2:16:59 Max: 2:57:59 SD: 0:09:45 *n = 58*
Forwards	Mean: 0:55:57 Min: 0:40:04 Max: 1:09:26 SD: 0:08:27 *n = 73*	Mean: 0:54:37 Min: 0:20:13 Max: 1:30:13 SD: 0:19:10 *n = 273*	Mean: 0:29:37 Min: 0:15:31 Max: 0:44:57 SD: 0:10:11 *n = 102*	Mean: 2:33:30 Min: 2:16:59 Max: 2:56:37 SD: 0:13:32 *n = 30*

5.5 Statistical analysis

IBM SPSS Statistics 29- software (International Business Machines Corp, New York, United States) were used for statistical analysis of the results and the data were processed with Microsoft Excel 2022 (Microsoft Corporation, Redmond, United States). Differences in the variables amount of load and intensity of load between ice practices and games for forwards and defensemen were compared using paired samples t-tests.

This test was chosen because the sample sizes in the study are at least 30, and the variables are normally distributed. This statistical analysis was also chosen because it compared the results within the same group. The group was assumed to be normally distributed because the sample size was so large. (Nummenmaa. 2008, 166-169.)

The limit for statistical significance was defined as follows. If the p-value is below 0.050, the difference is statistically nearly significant. If the p-value is below 0.010, the difference is statistically significant. If the p-value is below 0.001, the difference is statistically highly significant.

In the first analysis, the amount of forwards game workload was compared with the variable TRIMP on the ice practice of the game day morning, the ice practice on the day before the game, and the ice practice two days before the game. In the second analysis, the amount of forwards game workload was compared with the variable movement load on the ice practice of the game day morning, the ice practice on the day before the game, and the ice practice two days before the game.

In the third analysis, the amount of defensemen game workload was compared with the variable TRIMP on the ice practice of the game day morning, the ice practice on the day before the game, and the ice practice two days before the game. In the fourth analysis, the amount of defensemen game workload was compared with the variable movement load on the ice practice of the game day morning, the ice practice on the day before the game, and the ice practice two days before the game.

In the fifth analysis, the intensity of forwards game workload was compared using the variable TRIMP/min on the morning ice practice of the game day, the ice practice on the day before the game, and the ice practice two days before the game. In the sixth analysis, the intensity of forwards game workload was compared using the variable movement intensity on the morning ice practice of the game day, the ice practice on the day before the game, and the ice practice two days before the game.

In the seventh analysis, the intensity of defensemen game workload was compared using the variable TRIMP/min on the morning ice practice of the game day, the ice practice on the day before the game, and the ice practice two days before the game. In the eighth analysis, the intensity of defensemen game workload was compared using the variable movement intensity on the morning ice practice of the game day, the ice practice on the day before the game, and the ice practice two days before the game.

6 Results

6.1 Amount of load

6.1.1 Forwards

Figure 15 illustrate forwards average TRIMP values from ice practices and games. The workload in the game was higher than the workload in the morning ice practice on game day. The difference was found to be highly significant, p < 0.001. The workload in the game was higher than the workload in the ice practice day before the game. The difference was found to be highly significant, p < 0.001. Also, the workload in the game was higher than the workload in the ice practice two days before the game. The difference was found to be highly significant, p < 0.001.

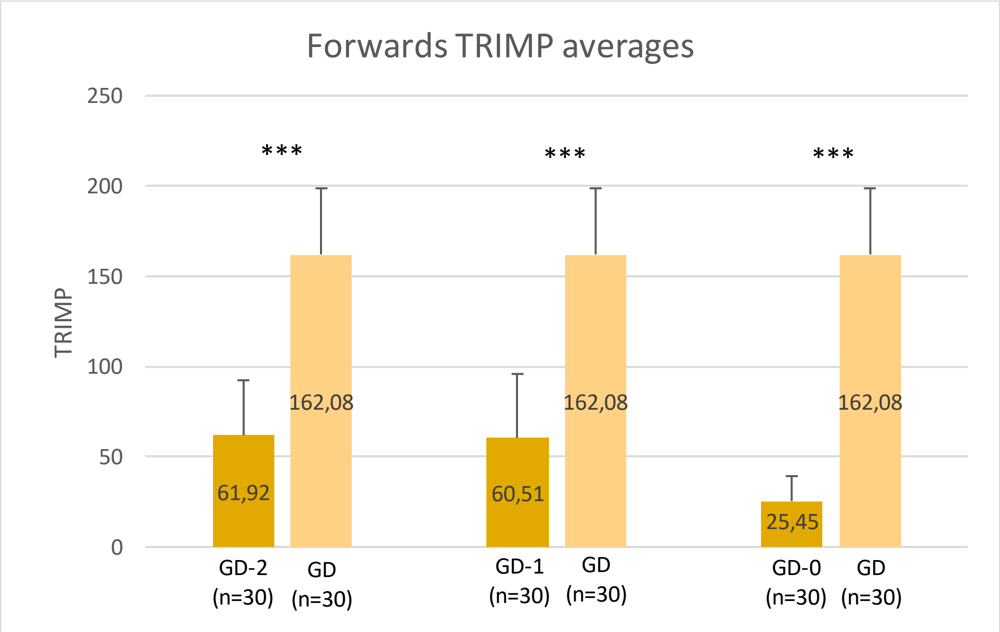

Figure 15. Forwards average TRIMP values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

Figure 16 illustrate forwards movement load. In the game was higher than the movement load in the ice practice on game day morning. The difference was found to be highly significant, p < 0.001. Movement load in the game was higher than the movement load in the ice practice the day before the game. The difference was found to be highly significant, p < 0.001. Movement load in the game was higher than the movement load in the ice practice two days before the game. The difference was found to be highly significant, p < 0.001.

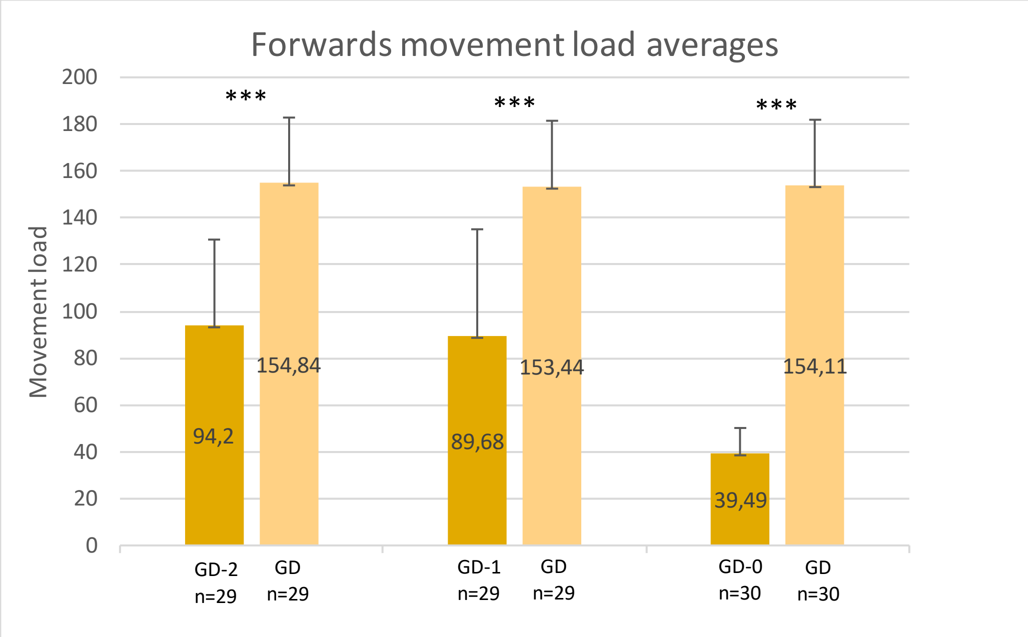

Figure 16. Forwards movement load average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

6.1.2 Defensemen

Figure 17 illustrate defensemen average TRIMP values from ice practices and games. Defensemen workload in the game was higher than the workload in the ice practice on game day morning. The difference was found to be highly significant, $p < 0.001$. The workload in the game was higher than the workload in the ice practice day before the game. The difference was found to be highly significant, $p < 0.001$. Also, the workload in the game was higher than the workload in the ice practice two days before the game. The difference was found to be highly significant, $p < 0.001$.

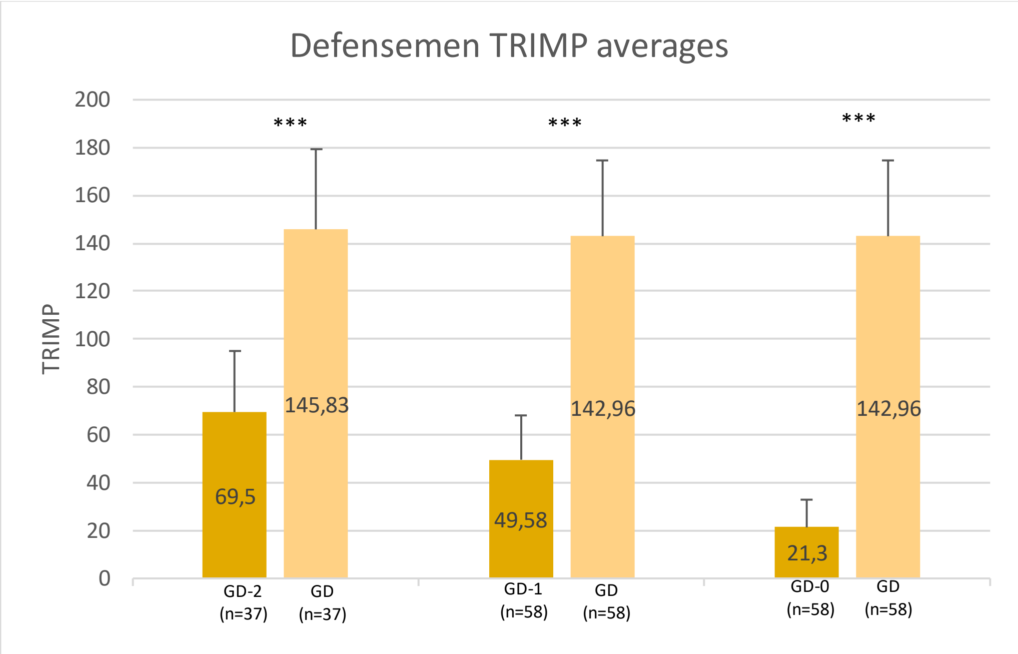

Figure 17. Defensemen TRIMP average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

Figure 18 illustrate defensemen movement load in the game was higher than the movement load in the ice practice on game day morning. The difference was found to be highly significant, $p < 0.001$. Movement load in the was higher than the movement load in the ice practice day before the game. The difference was found to be highly significant, $p < 0.001$. Movement load in the was higher than the movement load in the ice practice two days before the game. The difference was found to be highly significant, $p < 0.001$.

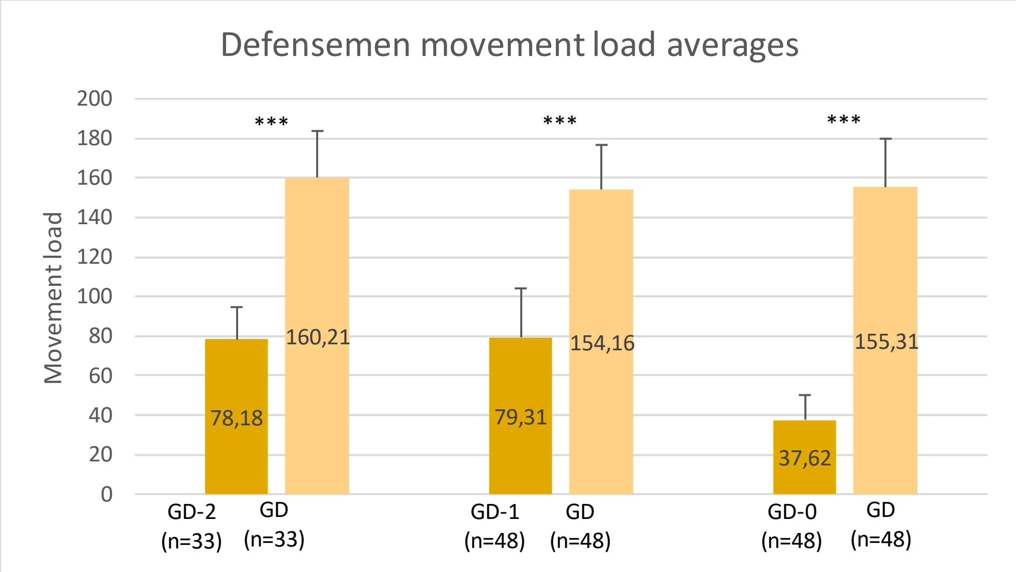

Figure 18. Defensemen movement load average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

6.2 Intensity of load

6.2.1 Forwards

Figure 19 illustrate forwards average intensity (TRIMP/min) in the game was higher than the intensity in the ice practice on game day morning. The difference was found to be highly significant, $p < 0.001$. Also, the intensity in the game was higher than the intensity in the ice practice the day before the game. The difference was not significant, $p = 0.084$. However, the intensity in the game was smaller than the intensity in the ice practice two days before the game. The difference was not significant, $p = 0.625$.

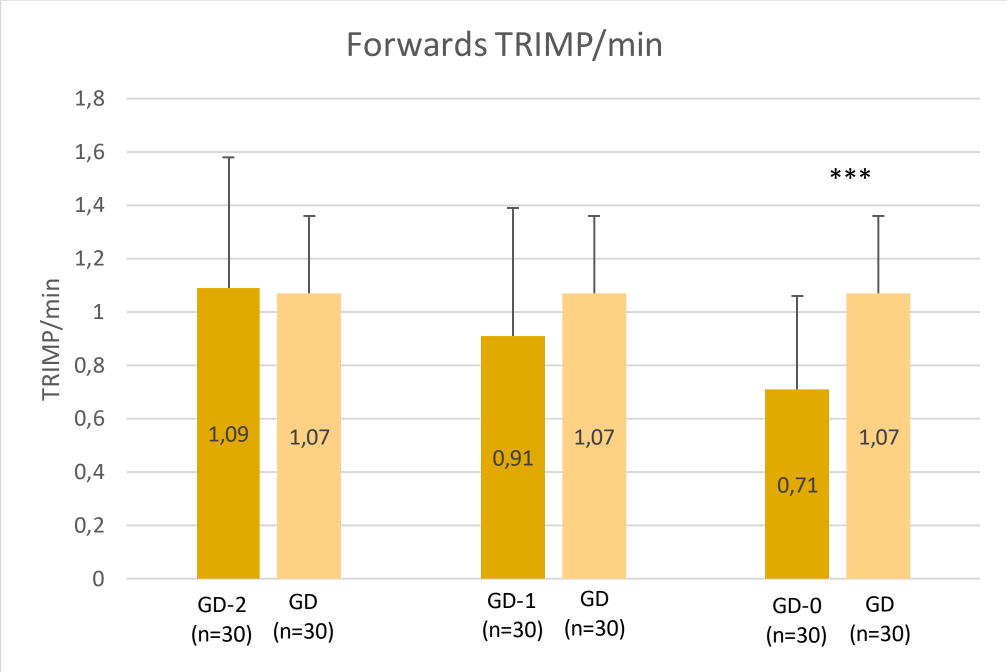

Figure 19. Forwards TRIMP/min average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

Figure 20 illustrate forwards average movement intensity from ice practices and games. Forwards average movement intensity in the game was lower than average movement intensity in the ice practice on game day morning. The difference was not significant, p = 0.150. Average movement intensity in the game was lower than the average movement intensity in the ice practice the day before the game. The difference was statistically significant, p = 0.003. Average movement intensity in the game was lower than the average movement intensity in the ice practice two days before the game. The difference was found to be highly significant, p < 0.001.

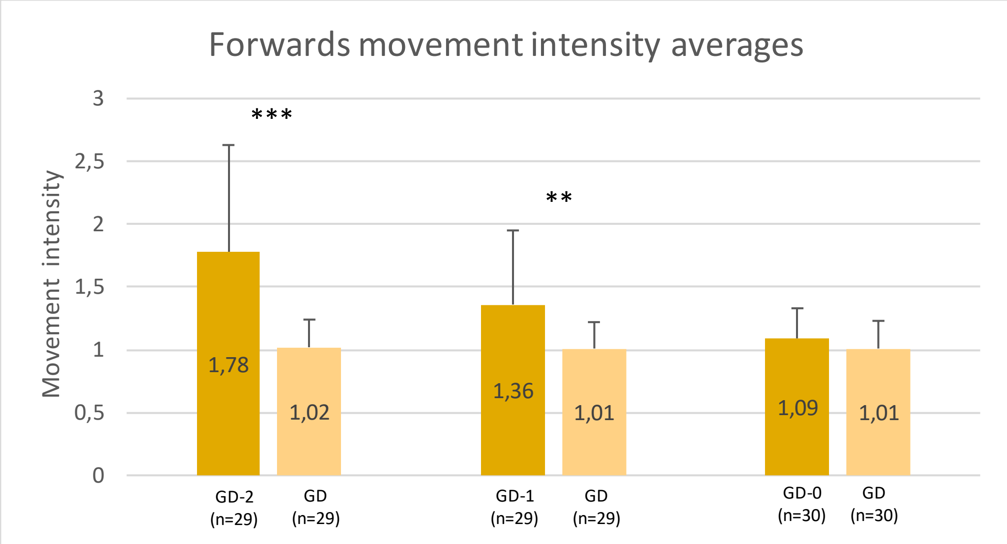

Figure 20. Forwards TRIMP/min average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

6.2.2 Defensemen

Figure 21 illustrate defensemen average intensity (TRIMP/min) in the was higher than in the ice practice on game day morning. The difference was found to be highly significant, p < 0.001. Also, the intensity of the intensity of the game was higher than the intensity in the ice practice the day before the game. The difference was not significant, p = 0.177. However, the average intensity in the game was lower than the intensity in the ice practice two days before the game. The difference was found to be significant, p = 0.002.

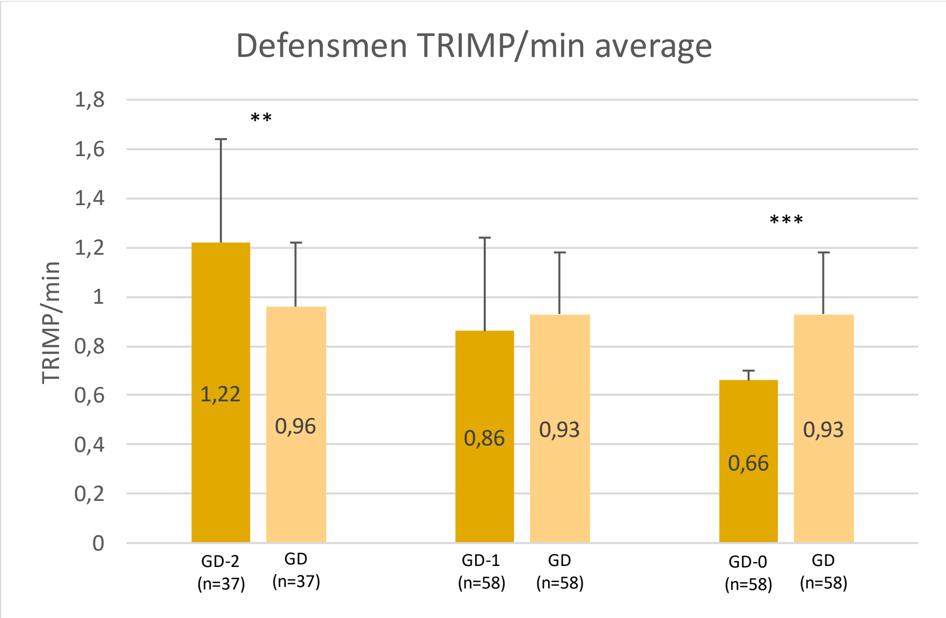

Figure 21. Defensemen TRIMP/min average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

Figure 22 illustrate defensemen average movement intensity from ice practices and games. Defensemen average movement intensity in the game was lower than average movement intensity in the ice practice on game day morning. The difference was statistically significant, p = 0.003. Average movement intensity in the game was lower than the average movement intensity in the ice practice the day before the game. The difference was not significant, p < 0.001. Average movement intensity in the game was lower than the average movement intensity in the ice practice two days before the game. The difference was found to be highly significant, p < 0.001.

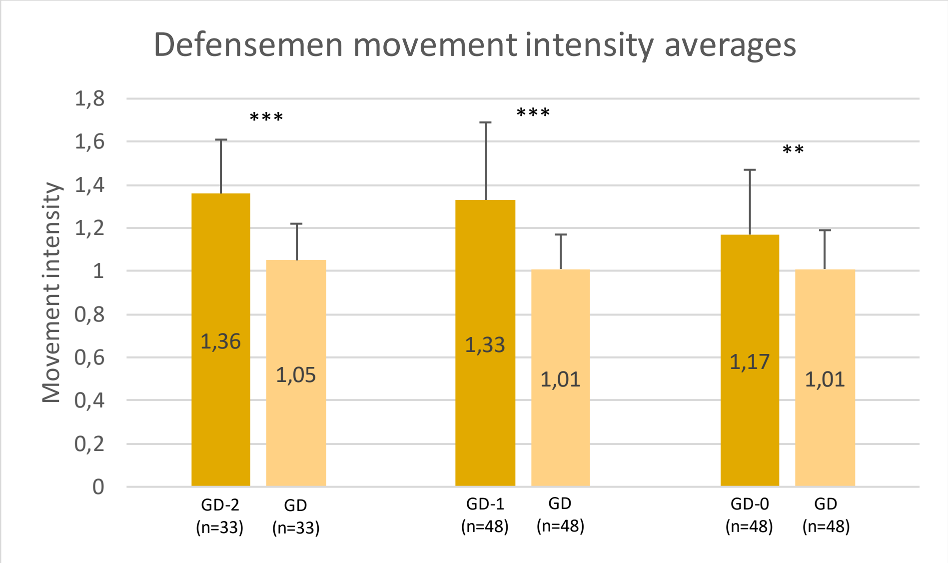

Figure 22. Defensemen movement intensity average values from ice practices and games. The values are averages, and the scatter bars represent the standard deviation. *** = p < 0,001, ** = p < 0,01, * = p < 0,05

7 Discussion

The purpose of this study was to examine how the amount of load and intensity of load in the ice hockey practice during the playing season differs in relation to the game amount of load and intensity in a professional ice hockey team. Goalies was not examined in this study. The research question in this study was how the amount of load and intensity of load in the ice practice differs compared to the amount and intensity of load in the game for forwards and how the amount of load and intensity of load in the ice practice differ compared to the amount and intensity of load in the game for defensemen. This study examined the amount of the loads and intensity of the load of ice hockey practices and games in a professional team which playing in the Finnish main league, Liiga. The key variables in the study were the amount of load (TRIMP and movement load) and the intensity of the load (TRIMP/min and movement intensity).

In the study both defenders and forwards had significantly higher loads (TRIMP and movement load) in the games compared to the loads accumulated in the ice practices. In the ice practice conducted two days before the game, the loads for both positions were the highest among the practice sessions, and the load decreased as the game approached.

In addition to the amount of load, another essential variable in the study was the intensity of the load (TRIMP/min and movement intensity). Based on the measurement results, defenders were found to have higher intensity in ice practice which was two days before the game than game according to the TRIMP/min variable. In other ice practice sessions, the intensity remained lower compared to game intensity. Another variable interpreting the intensity of the load for defenders was movement intensity which was higher in every ice practice session compared to the game. Both variables showed a decrease in intensity as the game approached, like the decrease in the amount of load. The data includes time spent on the bench and during intermissions, so it's possible that this might contribute to lower intensity variables during the game, as noted by Neeld & al. (2021) in their study on NCAA players, where data collection also included time spent on the bench and during intermissions. This could affect the intensity variables, so it would be interesting to collect data that separates the time spent on the bench and during intermissions.

For forwards, the intensity of the load measured by the TRIMP/min variable was found to be higher than game intensity only in the ice practice session conducted two days before the game. In other ice practice sessions, the TRIMP/min variable remained below game intensity. According to the study by Allard et al. (2022), the absolute game intensity of forwards is 15 % higher than that of defensemen, so forwards rarely train at the average game intensity on ice practice. Similarly to defenders, the other variable interpreting the intensity of the load for forwards, movement intensity, was higher in every ice practice session compared to the game, and it was again highest in ice practice which was two days before the game. As with the decrease in the amount of load as the game approached, the intensity also decreased as the game approached. Just like defenders, the data from games for forwards also includes time spent on the bench and during intermissions, which may potentially contribute to lower intensity in the game, as noted by Neeld & al. (2021) in their study. Also, Allard & al. (2022) point out in their study on AHL players that coaches may not always demand the same level of physical contact in practices as in games. For example, Hootman, Dick, & Agel (2007) found, from 16 years of National Collegiate Athletic Association (NCAA) injury surveillance data across 15 sports, that the injury rate in ice hockey practice was 8 times lower than in games. Although players use the same equipment in practices as in games, the research supports the notion that the level of physical contact required in ice hockey practices may not be as high as in games. Additionally, games involve a competitive outcome, which increases the element of competition. There is no data in this study on whether there has been competition during ice practices as part of the training. It could be interesting to investigate how different types of exercises and the competition elements or match simulations incorporated into them affect the training load and intensity in the ice practices.

The study's results also allow for comparing differences in amount of load and intensity of load between forwards and defensemen in both ice practices and games. Forwards' internal load TRIMP averages were higher than defensemen in the day before game ice practice and on the game day's morning ice practice. Additionally, in the game, forwards' TRIMP average was significantly higher than defensemen. These findings can be compared to previous research results, as noted by Neeld & al. (2020) in their study, where forwards accumulated significantly higher workloads across all seven measures (player load (PL), skating load (SL), explosive efforts (EE), high force strides (HFS), and player load per minute (PL/min), stride force/lb (ASF/lb) in practices and games. However, compared to the Neeld & al. (2018) study in this research defensemen had a higher TRIMP values than forwards in the ice practice conducted two days before the game. In ice practices, forwards have significantly higher average values of movement load variable compared to defensemen. However, in game, movement load variable is almost the same for both positions.

Both forwards and defensemen exhibit significantly lower loads with variables TRIMP and movement load in ice practices compared to games. Particularly, the internal and external loads during the morning ice practice on game days are very low, which is understandable considering the short duration of this specific practice compared to others and the game itself. Generally, the purpose of the morning ice practice on game days is to raise the team's physical readiness and get a feel for the evening match, rather than physically burdening the team too much.

When comparing the game workload and intensity between defensemen and forwards, it can be observed that defensemen generally exhibit lower intensity in the games compared to forwards. Previous studies support this finding. For instance, Allard & al. (2022) found in their study of AHL players that defensemen had lower intensity in the games compared to forwards. Additionally, Neeld & al. (2021) highlighted in their study of college players that forwards perform more high-intensity work compared to defensemen. Reinikainen (2021) also noted in their research that defensemen accumulate more skating in the low-intensity speed range during games compared to forwards, who accumulate more skating in the high-intensity speed range. These studies also support why professional teams often play with four forward lines but only three defensive pairs, resulting in defensemen accumulating more ice time than forwards. This is also supported by Allard & al. (2022), who found in their study that defensemen's typical time on ice has a higher number of shifts during the match (20,7 ± 2,3 vs. 15,3 ± 2,2 for forwards).

7.1 Practical applications

The results can be utilized in the planning of ice hockey team training during the playing season. When planning the training of teams, it is important to consider the type of workload different player positions experience during games and the workload these players receive during ice practices. For example, are there different drills on the ice for different player positions, or do forwards and defensemen have different tasks during ice practices? Or are the practices mainly focused on drills where all players perform the same tasks? Clubs, teams, and coaches should consider whether it is feasible, in terms of resources, to utilize existing tools such as TRIMP/min and movement intensity more effectively during training sessions, allowing coaches to adjust exercises as needed to achieve the desired training load and intensity. For instance, Neeld & al. (2021) propose that real-time monitoring of workload and intensity measurements enables coaches to manage brief rest intervals between drill repetitions or substitute players who unintentionally engage in excessive work.

Coaches should consider how ice practices affect the workload and intensity of their team's forwards and defensemen, and whether forwards receive enough workload and intensity comparable to the game. Can we create competition in ice practices, for example, using a scoring system that potentially increases intensity during ice practice while also simulating game situations to some extent? It is also possible to design exercises where substitutions occur not with a whistle, but in a manner like a game, such as on-the-fly changes or if the game is interrupted, for example, due to a goal being scored.

If there are several days before the game, it is advisable to increase the volume of ice training, as there is still plenty of time to recover before the match. Neeld & al. (2021) suggest in their study that three days before the game is still a good time to engage in high-volume ice training, allowing players ample time for recovery before the match. Coaches should also consider what kind of ice training would be beneficial in ice practices close to the game, so that fatigue does not accumulate excessively, which would impair match performance, but still matches the intensity of the game for different positions. Neeld & al. (2021) emphasizes that if high intensity of load is emphasized in the ice practice close to the game (GD-1), but with low volume, it may be possible to help players compete at a high work rate while also reducing residual fatigue.

The results can also be utilized in rehabilitating injured players back to playing condition, as they enable coaches or other personnel in charge of rehabilitation to better adjust the workload and intensity of on-ice training to align more closely with game demands, thereby determining when a player is ready to return to games (Neeld & al., 2021; Allard & al., 2022).

7.2 Further development

As a further development in load monitoring, it could be beneficial to gather more data on the relationship between external and internal physical load across different playing positions during ice hockey practices, various drills, and games, including different game situations and specifically across different periods. For instance, in the second period, teams may have a longer distance to change lines from their defensive zone compared to the first and third periods. In addition, it would be a more detailed division among players could involve distinguishing between top-line players and bottom-line players and examining how their loads differ in games and practices. As such, there is very limited evidence of such a division in the literature published so far. Additionally, examine how the workloads of players specializing in different situations compare to those who do not play specialized roles like power play and penalty kill could provide valuable insights. For example, in the study conducted by Neeld et al. (2021), top-line players had higher values in the following variables: player load (PL), skating load (SL), explosive efforts (EE), high force strides (HFS), and player load per minute (PL/min), but lower values in the variable average stride force/lb (ASF/lb) compared to bottom-line players. Therefore, it would be interesting to investigate whether this has an impact on load. Additionally, obtaining coaches' assessments of the load during both practices and games would provide valuable data, as existing research on ice hockey load is still limited. For example, Rintamäki (2024) concludes in their study that there was no clear trend of overestimation or underestimation of load by the coach observed in the study conducted on the U17 and U18 national teams.

In this study, the workload during the professional team's playing season was examined, where games are scheduled on weekdays and weekends due to the tight schedule of the regular season.

Therefore, a similar study would be interesting to conduct in a junior team, such as the U20 age group, where game days are mostly on weekends, allowing for more ice practices on multiple days before the match. In such a scenario, there would be more ice practices on multiple days leading up to the game, so it would be interesting to see how the load compares to the match load in this case.

7.3 The reliability and ethics of the study

When interpreting the results of this study, it is also important to assess the reliability of the methods used. In the study, data related to load was collected using Firstbeat Sports sensors, which players wore underneath their hockey gears during ice practices and games. Contacts and falls are very typical features of the sport, which means that it is also possible for the heart rate sensors worn underneath the gears might move or possibly even fall off during the performance, causing data collection to be interrupted. Consequently, there is a possibility that the load for an entire ice practice or game is not recorded for certain players. Additionally, there were some players did not wear sensors in every practice or game, resulting in a varying number of recordings from different practices and games, with some players having more recordings than others. Furthermore, playing times or the distinction between top-line and bottom-line players were not separately identified for the study, so it is possible that there is more data available, for example, from bottom-line players compared to top-line players, whose playing time may be higher than that of bottom-line players due to special situations or overtime periods in the regular season. During the data collection phase, measurements with over 10 % measurement errors have been removed prior to commencing the statistical analysis.

When interpreting the workloads of a professional team, it's important to note that the results of this study may not fully generalize to other teams playing in the same league. As noted by Allard & al. (2022) in their study, training philosophy, match tactics/strategy/scenario are contextual factors that can influence training methods and distribution. Additionally, in professional ice hockey, the need to win is paramount, which also affects training during the playing season, even in the short term.

When interpreting the results, it is important to note that the data collected from games covers the entire match, including intermissions and time spent on the bench. This is evident when looking at the duration of measurements in the game events. Therefore, it is possible that the recorded intensity of work during matches may be lower, as observed in Neeld & al. (2020), where average stride force/lb measures were higher in matches, suggesting on-ice work occurred at a higher intensity during matches compared to training. Neeld & al. (2020) suggest that game work rates may have been lower because the data was processed to include rest time on the bench and stoppages in play.

The team involved in this study remains anonymous for privacy reasons. The players in the team are represented in the research data anonymously using only ID numbers derived from the Firstbeat Sports sensors. This study is part of Marko Haverinen's dissertation research, and he acted as the data collector. Before sharing the data, players were categorized into forwards and defensemen, and personal information that could potentially identify the players was removed.

7.4 Own assessment of the thesis

This research provided me with a great deal of additional learning about monitoring training load in ice hockey. Particularly, it was interesting to study and learn more about how the load differs between forwards and defensemen both in ice practices and games. Through this study, I began to consider more and more what kind of training sessions would be beneficial to match the load, especially when there are several days until the game. As the game approaches, it's crucial to match the intensity to the level of the game, so the training session should be shorter to ensure that players have the energy for the game. The more intensity we can achieve for different playing positions, at least to the level required in the game, I believe players will also develop physiologically.

References

Allard, P., Martinez, R., Deguire, S. & Tremblay, J. 2022. In-season Session Training Load Relative to Match Load in Professional Ice Hockey. Journal of Strength and Conditioning Research. Feb 1;36(2):486-492. DOI: 10.1519/JSC.0000000000003490.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. 2017. Monitoring Athlete Training Loads: Consensus Statement. International Journal of Sports Physiology & Performance, 12, S2-161-S2-170. URL: https://journals.humankinetics.com/view/journals/ijspp/12/s2/article-pS2-161.xml?content=pdf. Accessed: 2 September 2023.

Brocherie F, Girard O, Millet GP. 2018. Updated analysis of changes in locomotor activities across periods in an international ice hockey game. Biology of Sport, 35 (3), 261.

Chiarlitti, N. A., Delisle-Houde, P., Reid, R. E.R., Kennedy, C. & Andersen, R. E. 2018. Importance of body composition in the national hockey league combine physiological assessments. The journal of strength and conditioning research, 32, 11, 3135-3142.

CHL 2023. The CHL Format. URL: https://www.championshockeyleague.com/en/about-us/chl-format. Accessed: 15 November 2023.

CHL 2023. About us. URL: https://www.championshockeyleague.com/en/about-us. Accessed: 15 November 2023.

Cox, M. H., Miles, D. S., Verde, T. J., Rhodes, E. C. 1995. Applied physiology of ice hockey. Sports Medicine, 19:184-201.

Davidson, A. 2021. Real-time TRIMP/min: How to use the Firstbeat live app feature in training. URL: https://www.firstbeat.com/en/blog/real-time-trimp-min/#:~:text=TRIMP%20stands%20for%20Training%20Impulse,represented%20by%20a%20single%20number. Accessed: 2 February 2024.

Douglas, A. S. & Kennedy, C. R. 2020. Tracking In-Match Movement Demands Using Local Positioning System in World-Class Men's Ice Hockey. Journal of strength and conditioning research 34, 3, 639–646.

Eliteprospects 2023. Leagues. URL: https://www.eliteprospects.com/leagues. Accessed: 15 november 2023.

Ferland, P-M., Marcotte-L'Heureux, V., Roy, P., Carey, V., Charron, J. & Lagrange, S. 2021. Maximal Oxygen Consumption Requirements in Professional North American Ice Hockey. Journal of Strength & Conditioning Research, 35, pp. 1586–1592.

Firsbeat. Firstbeat Sports Premium. Movement Load and Movement Intensity. External load metrics to complete the training picture. URL: https://content.firstbeat.com/en/firstbeat-sports-movement-load. Accessed: 12 April 2024.

Firstbeat. Learning Center: Interpreting Training Data. URL: https://www.firstbeat.com/en/professional-sports/learning-center/interpreting-training-data/#TRIMP. Accessed: 2 April 2024.

Firstbeat. Real-time TRIMP/min: How to Use the Firstbeat Sports App Feature in Training. URL: https://www.firstbeat.com/en/blog/real-time-trimp-min/. Accessed: 25 January 2024.

Firstbeat. Training Load Guide for Ice Hockey Coaches. Firstbeat Technologies. Jyväskylä.

Firstbeat. Understanding Athlete Training Load. Firstbeat Technologies. Jyväskylä.

Foster, C., Rodriguez-Marroyo, J, A. & De Koning, J, J. 2017. Monitoring Training Loads: The Past, the Present, and the Future. International Journal of Sports Physiology and Performance. 12, pp. 2-8. URL: https://journals.humankinetics.com/view/journals/ijspp/12/s2/article-pS2-2.xml. Accessed: 12 October 2023.

Gastin, P. B. 2001. Energy system interaction and relative contribution during maximal exercise. Sports Medicine 31, 10, pp. 725–741.

Gharbi, Z., Dardouri, W., Haj-Sassi, R., Chamari, K. & Souissi, N. 2015. Aerobic and anaerobic determinants of repeated sprint ability in team sports athletes. 32, 3, pp. 207-12. URL: https://pubmed.ncbi.nlm.nih.gov/26424923/. Accessed: 20 October 2023.

Gustavsson, K Å, 2002. Elitishockeystudien- delrapport 2, krav och kapacitetprofil hos svenska elitishockeyspelaren. Svenska ishockeyförbundet. Sveriges olympiska kommitte. 2002.

Hakkarainen, H. 2015b. Nopeuden harjoittaminen. In Danskanen, K. (eds.) Lasten ja nuorten hyvä harjoittelu, pp. 236-252. VK-Kustannus Oy. Lahti.

Halson S. L. 2014. Monitoring training load to understand fatigue in athletes. Sports medicine 44, pp. 139–147.

Harper, D.J., Carling, C. & Kiely, J., 2019. High-Intensity Acceleration and Deceleration Demands in Elite Team Sports Competitive Match Play: A Systematic Review and Meta-Analysis of Observational Studies. Sports Medicine, 49, 12, pp. 1923–1947.

Haugen, T., Hopkins, W., Breitschädel, F., Paulsen, G. & Solberg, P. 2021. Fitness Tests and Match Performance in a Male Ice Hockey National League. International Journal of Sports Physiology and Performance 3, pp. 1-8.

Haverinen, M & Leppänen, M. Kuormituksen seuranta. URL: https://terveurheilija.fi/harjoittelu/kuormituksen-seuranta/. Accessed 2 November 2023.

Hootman JM, Dick R, Agel J. 2007. Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. Journal of athletic training. 42. 311–319, URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1941297/. Accessed: 15 April 2024.

IIHF. 2010. Welcome to ice hockey. A concise guide to junior ice hockey. IIHF. Switzerland. URL: https://blob.iihf.com/iihfmedia/iihfmvc/media/downloads/sport%20files/recruitment%20program/brochures/welcome-to-ice-hockey-english.pdf. Accessed. 30 August 2023

IIHF Worlds. 2023. 4 May 2016. Intro to ice hockey. Online video. URL: https://www.youtube.com/watch?v=TGiaFDQ8HfA&t=119s. Accessed: 30 august 2023.

IIHF. 2022. Official rule book. URL: https://blob.iihf.com/iihf-media/iihfmvc/media/downloads/rule%20book/220721_iihf_rulebook_v22.pdf. Accessed: 10 August 2023

IIHF 2023. History of ice hockey. URL: https://www.iihf.com/en/statichub/4808/history-of-ice-hockey. Accessed: 15 November 2023.

Impellizzeri, F. M., Marcora, S. M. & Coutts, A. J. 2019. Internal and External Training Load: 15 Years On. International Journal of Sports Physiology and Performance. URL: https://blog.performancelab16.com/wp-content/uploads/2023/02/ijspp.2018-0935.pdf.

Jackson, J., Snydmiller, G., Game, A. & Gervais, P. 2016. Movement characteristics and heart rate profiles displayed by female university ice hockey players. International Journal of Kinesiology and Sports Science 4, 1, pp. 43-54.

Korte, V. 2020. Relationships between general and specific physical characteristics and match-related indicators in elite finnish ice hockey players at different playing positions. Master`s Thesis. University of Jyvaskyla. Science of Sports Coaching and Fitness Testing. URL: https://jyx.jyu.fi/bitstream/handle/123456789/69917/URN%3aNBN%3afi%3ajyu-202006154161.pdf?sequence=1&isAllowed=y. Accessed: 27 February 2024.

Kutáč, P & Sigmund, M. 2015. A Comparison of somatic variables of elite ice hockey players from the Czech ELH and Russian KHL. Journal of Human Kinetics volume 45/2015. URL: https://www.researchgate.net/publication/276063716_A_Comparison_of_Somatic_Variables_of_Elite_Ice_Hockey_Players_from_the_Czech_ELH_and_Russian_KHL. Accessed. 27 February 2024.

Laaksonen, A. & Vähälummukka, M. 2016. Jääkiekon lajianalyysi ja valmennuksen ohjelmointi: Ottelun fysiologinen kuormittavuus. In A. Mero, A. Nummela, S. Kalaja & K. Häkkinen (eds.). Huippu-urheiluvalmennus – Teoria ja käytäntö päivittäisvalmennuksessa. pp. 564–579. VK-Kustannus Oy. Lahti.

Lignell, E., Fransson, D., Krustrup, P. & Mohr, M. 2018. Analysis of high-intensity skating in top-class ice hockey match-play in relation to training status and muscle damage. Journal of Strength and Conditioning Research 32, 5, pp. 1303-1310.

Liiga. 2023. Finnish Elite Ice Hockey League Season 2023–2024. URL: https://liiga.fi/en/schedule?kausi=2023-2024&sarja=runkosarja. Accessed: 30 August 2023.

Lovell, T. W. J., Sirotic, A. C., Impellizzeri, F. M. & Coutts, A. J. 2013. Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. International Journal of Sports Physiology and Performance, 8, 1, pp. 62–69.

Manners T.W. 2004. Sport-specific training for ice hockey. Strength Cond J 26, pp. 16–21.

McGuican, Mike. 2017. Monitoring Training and Performance in Athletes. ed. Human Kinetics. pp. 69-101.

McGuican, Mike. 2017. Monitoring Training and Performance in Athletes. ed. Human Kinetics. pp. 189-201.

McLaren, S., Macpherson, T., Coutts, A., Hurst, C., Spears, I. & Weston, M. 2018. The relationships between internal and external measures of training load and intensity in team sports: a meta-analysis. Sports Medicine, 48, 3, pp. 641–658.

Montgomery, D. L. 1988. Physiology of ice hockey. Sports Medicine, 5, 2, pp. 99-126.

Neeld, K. 2018. Preparing for the Demands of Professional Hockey, Strength, and Conditioning Journal: 40. 1.

Neeld, K., Peterson, B., Dietz, C., Cappaert, T. & Alvar, B. 2021. Differences in External Workload Demand between Session Types and Positions in Collegiate Men's Ice Hockey. International Journal of Kinesiology & Sports Science.

Nicolella, D, P., Torres-Ronda, L., Saylor, K, J. & Schelling, X. 2018. Validity and reliability of an accelerometer-based player tracking device. PLOS ONE 13, 2. URL: https://doi.org/10.1371/journal.pone.0191823. Accessed: 13 April 2024.

Nightingale, S. & Douglas, A. 2018. Ice Hockey. Turner, A. (eds.) Routledge Handbook of Strength and Conditioning: Sport-Specific Programming for High Performance. New York: Routledge, pp. 157–177.

Nightingale, S. C. 2014. A Strength and Conditioning Approach for Ice Hockey. Strength and conditioning journal 36, 6, pp. 28–36.

Noonan, BC. 2010. Intragame Blood-Lactate Values During Ice Hockey and Their Relationships to Commonly Used Hockey Testing Protocols. Journal of Strength and Conditioning Research 24, 9, pp. 2290-2295.

Nummenmaa, L. 2008. Käyttäytymistieteiden: Tilastolliset menetelmät. 1.-4th ed. Tammi. Vammala.

Polar. Mitkä ovat erilaisten sykkeenmittaustapojen edut ja haitat verrattuna toisiinsa? URL: https://support.polar.com/fi/support/what_are_the_pros_and_cons_of_wrist_based_heart_rate_measurement_and_measuring_heart_rate_with_a. Accessed: 4 April 2024.

Reinikainen, M. 2021. In-season variation of skating load at different playing positions in male elite ice hockey. A single season longitudinal study. Master`s thesis. University of Jyvaskyla. Faculty of Sport and Health Sciences. URL: https://jyx.jyu.fi/handle/123456789/78973. Accessed: 28 January 2024.

Renfree, A., Casadob, A & McLaren, S. 2021. Re-thinking athlete training loads: would you rather have one big rock or lots of little rocks dropped on your foot? Research in sports medicine. VOL. 30, NO. 5, 573–576 URL: https://www.researchgate.net/publication/349957936_Re-thinking_athlete_training_loads_Would_you_rather_have_one_big_rock_or_lots_of_little_rocks_dropped_on_your_foot. Accessed: 4 April 2024.

Rintamäki, P. 2024. Erilaisten jääharjoitteiden kuormittavuus kansainvälisen tason juniorijääkiekkoilijoilla. Master`s thesis. University of Jyvaskyla. Faculty of Sport and Health Sciences. Accessed: 3 April 2024.

Stanula, A., Roczniok, R., Maszczyk, A., Pietraszewski, P. Zajac, A. 2014. The role of aerobic capacity in high-intensity intermittent efforts in ice-hockey. Biology of Sport. 31. pp. 193-199.

Stark, G. Firstbeat. Movement Load: Add Valuable Context to Internal Load Data. URL: https://www.firstbeat.com/en/blog/movement-load/?hsLang=en. Accessed: 30 February 2024.

Summanen, R. & Westerlund, E. 2001. Let´s Beat Them In Ice Hockey. Polar Electro Oy. Kuopio.

Thorpe, R.T., Atkinson, G. Drust, B., Gregson, W. 2017. Monitoring Fatigue Status in Elite Team-Sport Athletes: Implications for Practice. International Journal of Sports Physiology and Performance, 12, pp. 2-34. Human Kinetics.

Tiikkaja, J. 2002. Aerobinen, anaerobinen ja neuromuskulaarinen suorituskyky sekä sykevaihtelu pelikauden aikana jääkiekkoilijoilla. Master`s thesis. University of Jyvaskyla. Faculty of Sport and Health Sciences. Accessed: 30 September 2023.

Vigh-Larsen, J. F., Beck, J. H., Daasbjerg, A., Knudsen, C. B., Kvorning, T., Overgaard, K., Andersen, T. B. & Mohr, M. 2019. Fitness characteristics of elite and subelite male ice hockey players: A cross-sectional study. Journal of Strength & Conditioning Research 33, 9, pp. 2352-2360.

Vigh-Larsen, J. F., Ermidis, G., Rago, V., Randers, M. B., Fransson, D., Nielsen, J. L., Gliemann, L., Piil, J. F., Morris, N. B., DE Paoli, F. V., Overgaard, K., Andersen, T. B., Nybo, L., Krustrup, P. & Mohr, M. 2020. Muscle Metabolism and Fatigue during Simulated Ice Hockey Match-Play in Elite Players. Medicine and Science in Sports and Exercise 52, 10, pp. 2162-2171.

Vigh-Larsen JF & Mohr M. 2022. The physiology of ice hockey performance: An update. Scand J Med Sci Sports. 00:1-14.

Villemejane, T. 2009. Strength, power, and speed production of lower limbs during on and off ice tests in hockey players. Master`s thesis. University of Jyvaskyla. Faculty of Sport and Health Sciences. Accessed: 30 September 2023.

Wisløff, U., Helgerud, J. & Hoff, J. 1998. Strength and endurance of elite soccer players. Medicine & Science in Sports & Exercise 30, 3, pp. 462-467.