BODY CHECKING INTO THE BOARDS IN ICE HOCKEY – VELOCITIES, HEAD ACCELERATIONS AND BOARD BEHAVIOUR

Pontus Joentausta

Master's thesis in Biomechanics
Faculty of Sport and Health Sciences
University of Jyväskylä
Autumn 2022
Supervisors: Janne Avela, Timo Rantalainen

ABSTRACT

Joentausta, P. 2022. Body checking into the boards in ice hockey – velocities, head accelerations and board behaviour. Faculty of Sport and Health Sciences, University of Jyväskylä, Master's thesis, 48 pp., 2 appendices.

Intoduction: Ice hockey is a fast-paced game where body checking (tackling) is allowed. Body checks are an important part of the game in men's elite level. However, body checks are reason for many injuries such as concussions. Contact with ice hockey rink board causes often injuries as well. There has been research and change towards more flexible board systems to prevent injuries during last years. There is evidence that more flexible boards decrease head and shoulder injuries. This study focuses on body checking towards boards and the study aims to find out checking velocities, board behaviour and head accelerations during a body check at boards.
Methods: Competitive ice hockey players from 6 different age groups were recruited to perform body checking drill. U14 was the youngest group, and the oldest group was professional adult players from the highest level in Finland, Liiga. All groups performed body checking drill at least 18 times and body checks were filmed with high-speed-cameras with framerate of 250 Hz. Besides that, 7 ice hockey matches were filmed with the same setup. Player velocities, peak head accelerations, and board and glass behaviour were measured.
Results: Defender's (player who checks) perpendicular velocity was the smallest in U14 group (avg = 2,79 m/s) and the highest in U18 group (avg = 3,50 m/s) but the matches showed the highest average of 3,73 m/s. Player speed average was between 4 – 6 m/s in all groups among puck holders (player who receives the check) and defenders. In peak head accelerations all averages were between 60 and 75 m/s^2 among defenders and averages were between 72 and 91 m/s^2 among puck holders. U18 had the highest averages but U15 had the highest single value of 170 m/s^2. Board stopping distance averages were from 0,81 cm to 2,45 cm in the element part where U14 had the smallest average and Liiga group had the highest average. From the glass part it was the same with values of 1,78 cm to 4,72 cm.
Discussion & Conclusions: The biggest differences between age groups in results are in board behaviour as it was expected. Velocity differences were also as hypothesised but head acceleration differences were smaller than expected. Important aspect from head accelerations is that younger players had much more variation in head accelerations which is due to inexperience in body checking, or board behaviour, or both. More flexible board could lower head accelerations, but it is debatable if the main difference is because of board flexibility or inexperience among players. The body checking drill corresponded well to match situations with exception that drill executions were done with little bit slower perpendicular velocities.

Key words: ice hockey, player safety, body check, tackle, head accelerations, ice hockey board

TIIVISTELMÄ

Johdanto: Jääkiekko on nopeatempoinen joukkuelaji, jossa taklaaminen on sallittua. Vartalotaklaukset ovat tärkeä osa peliä miesten ammattilaistasolla. Kuitenkin taklaukset aiheuttavat paljon loukkaantumisia, kuten aivotärähdyksiä. Törmäykset kaukalon laitaan saa aikaan myös usein loukkaantumisia. Joustavampia kaukalon malleja on tutkittu viime vuosina ja vähitellen monet kaukalot on vaihdettu joustavampiin. On tieteellistä näyttöä, että joustavammat kaukalot vähentävät olkapää- ja päävammojen määrää. Tämä tutkimus keskittyy laitaan kohdistuviin taklauksiin tarkoituksena selvittää taklausnopeuksia, laidan käyttäytymistä ja pään kiihtyvyyksiä kyseisten taklausten aikana.
Mentelmät: Jääkiekon kilpailutoiminnassa mukana olevia ryhmiä rekrytoitiin mukaan tutkimukseen kuudesta eri ikäryhmästä. Nuorimmat olivat U14 joukkueessa pelaavia ja vanhimmat Suomen pääsarjatasolla, Liigassa, ammatikseen pelaavia aikuisia. Kaikki ryhmät tekivät useita suorituksia taklausharjoitetta ja taklaukset videoitiin suurnopeuskameroilla kuvanopeuden ollessa 250 kuvaa sekunnissa. Taklausharjoitteiden lisäksi seitsemän jääkiekko-ottelua kuvattiin samalla tavalla. Pelaajien taklausnopeudet, pään kiihtyvyydet sekä laidan ja pleksin käyttäytymistä mitattiin.
Tulokset: Taklaajan kohtisuora nopeus laitaa kohti oli pienin U14 ryhmässä (keskiarvo = 2,79 m/s) ja korkein U18 ryhmässä (keskiarvo = 3,50 m/s), mutta otteluiden keskiarvo oli kaikista korkein (3,73 m/s). Pelaajien resultanttinopeuden keskiarvot olivat 4–6 m/s kaikissa ryhmissä taklaajien ja taklattavien osalta. Pään huippukiihtyvyyksien keskiarvot olivat 60–75 m/s^2 taklaajilla ja 72–91 m/s^2 taklattavilla. U18 ryhmällä oli suurimmat keskiarvot pään huippukiihtyvyyksissä, mutta U15 ryhmällä oli korkein yksittäinen arvo (170 m/s^2). Laidan siirtymissä keskiarvot olivat 0,81–2,45 cm elementin osalta ja 1,78–4,72 cm pleksin osalta. Molemmissa pienimmät arvot olivat U14 ryhmältä ja suurimmat arvot Liiga ryhmältä.
Pohdinta ja yhteenveto: Suurimmat erot ikäryhmien välisissä tuloksissa ovat laidan siirtymissä oletetusti. Nopeuseroavaisuuksissa hypoteesi osui myös oikeaan, mutta pään kiihtyvyyksien osalta erot olivat pienempiä kuin oli odotettua. Tärkeä huomio on, että nuorimmilla pään kiihtyvyyksissä oli paljon hajontaa, mikä johtunee kokemattomuudesta taklauksissa tai laidan joustamattomuudesta tai molemmista. Joustavammat laidat voisivat pienentää pään kiihtyvyyksiä, mutta on kyseenalaista, että onko merkittävämpi tekijä pelaajien kokemattomuus ja vai suhteellisen joustamaton laitarakenne. Taklausharjoite vastasi hyvin pelitilanteessa olleita taklauksia sillä poikkeuksella, että otteluissa taklaajien kohtisuora nopeus oli hieman korkeampi.

Avainsanat: jääkiekko, pelaajaturvallisuus, taklaus, pään kiihtyvyys, kaukalo

ACKNOWLEDGEMENTS

I would like to thank several directions. First, thanks belong to my supervisors from the University of Jyväskylä. Janne Avela, who introduced this possibility to me to get into this interesting project and helped with organizing. Timo Rantalainen who was big help in methodological questions through measurements and analysis. Thanks go to fellow students as well who helped with measurements.

Thanks to Raita Sports Co Ltd, which was funding the project. Especially Tuomo Hyvärinen deserves to be mentioned. He helped much in the beginning to make it possible to get the best possible environment and setting for the research. Thanks to all other people in Raita Sport Co Ltd as well who helped with the project.

Last, big thanks to JYP Liiga and Jyp Juniorit. Several persons from these organisations helped to arrange things and subjects that measurements could be done. Especially all players who participated from juniors to adults deserve big thanks. Without them this research could not been done.

CONTENT

1 INTRODUCTION

Ice hockey is a team game which includes fast-paced situations on ice. Besides fast skating it includes change of directions and many contacts. Even though physical abilities are important in ice hockey, high level of different skills is the most important thing. Understanding the game, puck handling, balance and skating skills are very important to perform well in the game. (Rouvali 2014, Pohjanvirta 2021.)

Ice hockey is an Olympic sport. It has been played in Olympics since 1920. Women's ice hockey started in Olympics 1988. Besides Olympics, ice hockey is played annually in world championships. There are also World Junior Championships for men under 20 and 18. For juniors in women there is under 18 world championship. In addition to international tournaments, ice hockey is played in many national leagues. The most famous is National Hockey League (NHL) in North America, but many northern Europe countries have professional ice hockey league. (Fishcler et al. 2020.) In NHL players average salary is around 3 million US dollars per year and franchise value of NHL team is approximately from 300 million to 1500 million US dollars. (Statista 2021a, Statista 2021b.) In the top professional league in Finland (Liiga) average player salary is around 75 000 Eur per year and average number of live spectators is about 4000 (Iltalehti 2018, Liiga 2021).

Contacts are part of sport in many ball games, and they can lead to an injury (Yde & Nielsen 1990). Ice hockey is not an exception, it is one of those sports where tackling with high speed is allowed in rules in men's matches (IIHF 2019). The relationships between contacts and injuries can be seen in many studies throughout the history of ice hockey (Mölsä et al. 1997, Tuominen et al. 2017a, Lynall et al. 2018). The nature of tackling, known as body checking in ice hockey, is different to other sports because of boards on the edge of the ice hockey rinks and high proportion of body checks take place towards those dasher boards. Ice surface and skating provide also different biomechanics in body checking compared to other contact sports (Poutiainen 2012).

This research will focus on body checking at rink boards. There are lot of research on injury prevalence and concussions but not comprehensive biomechanical analysis on body checking in literature. Bjering (2019) analysed body checking velocities where injuries happen, and average velocities were 6.55 m/s for player who checked and 4.59 m/s for injured player who received the check. Poutiainen et al. (2014) measured body checking velocities as well in their research, but they did not publish exact values of those body checks. They used 1.33, 2.54 and 3.37 m/s velocities in their board property experiments. Those values were average body checking velocities that were measured during matches towards boards. Among ice hockey coaches, there is feeling that velocities during matches and in body checks have increased in past years. Reason for that could be more flexible dasher boards which provide smaller injury risk in high body checking velocities.

The ice hockey board used to be very stiff and non-flexible structure before decade of 2010. Nowadays, there has been more development towards more flexible boards. Especially flexibility of the board has increased in the glass part of the board. (Marino & Potvin 2002, Poutiainen et al. 2014). This trend of softer boards has been seen to be a reason for smaller injury prevalence, especially in concussions and shoulder injuries. (Tuominen et al 2017a, Tuominen et al. 2017b.) The old reference boards gives 17 % to 73 % higher peak forces in impacts compared to current flexible boards according to previous researches (Marino & Potvin 2002, Poutiainen et al. 2014).

Higher forces, accelerations and velocities increase risks of injury (Zatsiorsky 2000). Making board contacts to have smaller forces and accelerations could then reduce injury risk in body checking situations. It is known in ice hockey that changing board system can lead to different forces and biomechanical loading (Poutainen et al. 2014, Schmitt et al. 2018) With knowledge of forces acting on player in collisions, it could be possible to make board checking situations safer with changes in boards, rules, or in player skills.

2 ICE HOCKEY

Ice hockey match consists of two teams which each have usually 6 players on ice. One of the players is goalkeeper. The idea is to get the puck, 156 – 170 grams of vulcanized rubber, to goal with the use of stick, which is made from composites such as carbon fiber nowadays. Players have padding under their uniforms to protect some body parts. (Fischler et al. 2020, IIHF 2019) In the following chapter some rules are gone through shortly. Checking rules are reviewed in chapter 3.1.

2.1 Playing environment and equipment

There are some details in rules of ice hockey that vary in different leagues but most of rules are the same. One important aspect to the nature of the game is the size of the rink. In North America, the rink is usually narrower (26 m) than in Europe (28 – 30 m) (Länsi-Suomi 2016, NHL 2020) Both dimensions are within the rules of IIHF which say that the width should be 25 – 30 m (IIHF 2019). So, rules of IIHF are introduced in this chapter.

Dimensions of rink are represented in the figure 1. Briefly, the length of the rink should be 60 meters and width 25 to 30 meters. So called attacking zones should be 22,86 meters long and thus center area should be 14,28 meters long. On the edge of the playing surface there must be rink boards. The board must contain three parts. In the bottom there must be so called kick plate which should be 15 – 25 cm high as a part of the board frame. The board element must be 107 cm high from ice. And on top of that there should be protective glass. The glass height must be 2.4 meters at the areas close to goal. (IIHF 2019.) Figure 2 presents board dimensions.

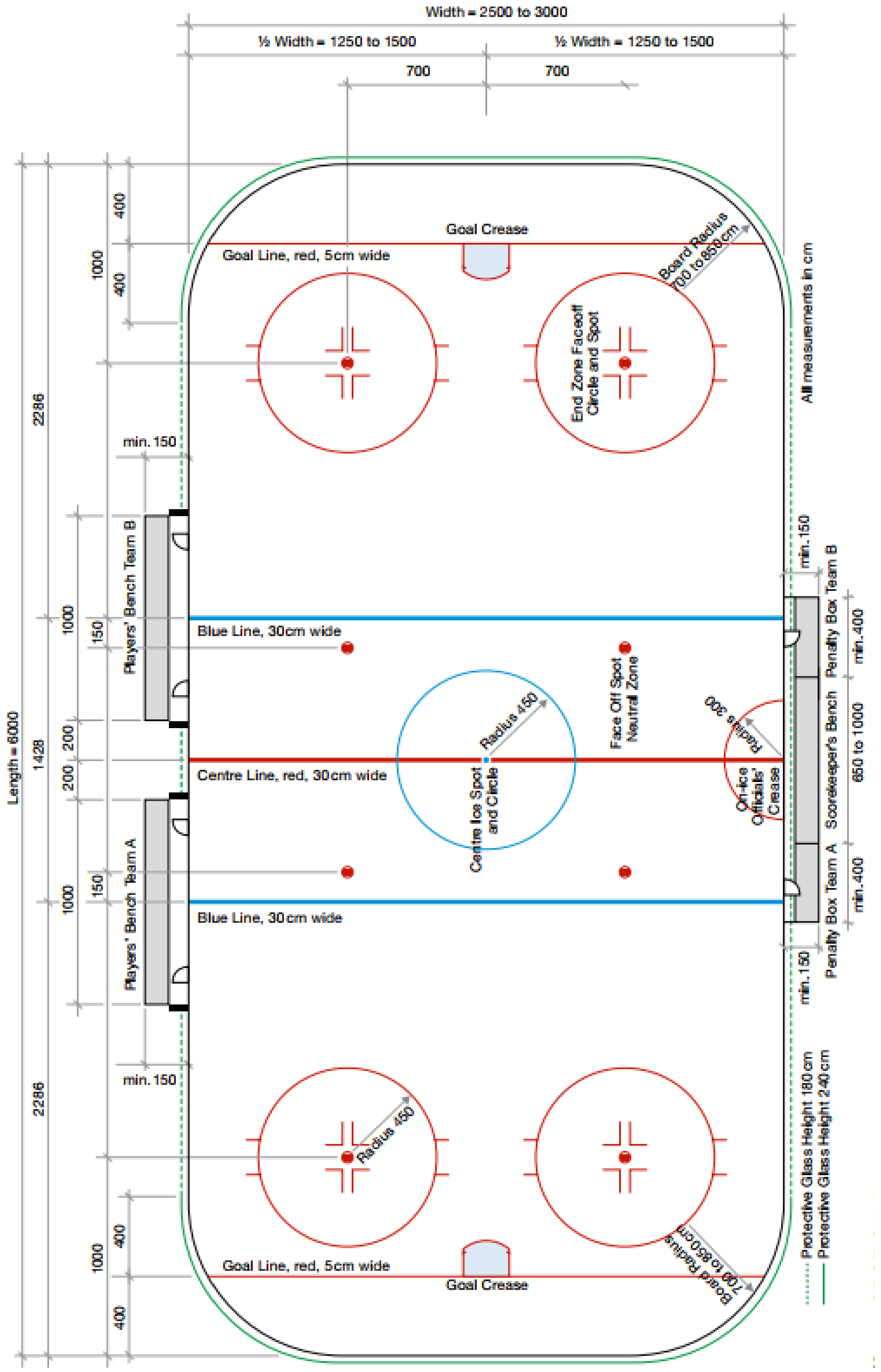

FIGURE 1. Dimensions of the rink (IIHF 2019).

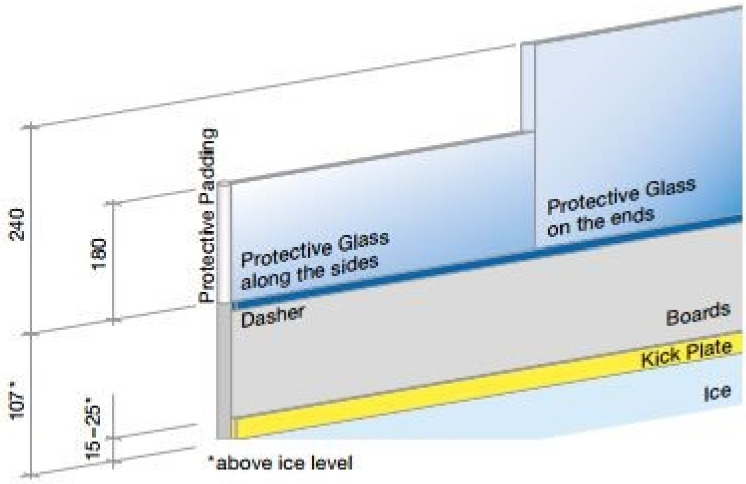

FIGURE 2. Properties and dimensions of rink board (IIHF 2019).

The match consists of three 20-minute periods and the winner is the team which scored more goals. In case of tie, overtime or penalty shootout can be played. The match clock is running only when the puck is in play. Teams are allowed to substitute players always with some exceptions. (IIHF 2019). Average amount of goals in a match is around 5 in Finnish Liiga (Liiga 2021).

Principles of the game are same for adults and juniors and the size of rink and goals are same. Among youngest juniors, body checking is not allowed. For example, in Finland body checking is not allowed in U12 group or younger. (Suomen jääkiekkoliitto 2020.) Body checking is prohibited in women’s ice hockey also (Suomen jääkiekkoliitto 2018).

A player must wear protective equipment which is introduced here. In addition to these rules there are some extra requirements for women and juniors. Adult men can use also protective things which are compulsory only for juniors, such as mouth guards and full visors. Following equipment is compulsory for everyone: Elbow pads, helmet, facial protection (minimum visor), gloves, shin pads, skates, stick, uniform. (IIHF 2019.) Besides them jockstraps, mouthguards and shoulder pads are commonly in use (Fischler et al. 2020). Mouthguards are compulsory for juniors under 20 years. Neck protection and full-face protection is also compulsory for juniors under 18 years. (IIHF 2019.)

2.2 Nature of the game

Ice hockey game is intense and fast-paced game. It consists of many breaks during period when the game is stopped. The game can be stopped for various reasons such as fauls, offsides or goalie holding the puck. (Fischler et al. 2020, Twist & Rhodes 1993.) The match event lasts usually over two hours even though the match clock gives only 60 minutes of play time. Breaks during and between periods increase the duration of the event. From player perspective of view the event can last up to four hours if all preparations and cool-down procedures are counted. (Rouvali 2014.)

Ice hockey player performs many short shifts during the match. Average time for one shift is 45 – 90 seconds. One shift includes many high-intensity bursts. (Rouvali 2014, Twist & Rhodes 1993, Brocherie et al. 2018.) According to Lignell et al. (2017) in NHL average distance covered during match is 4,6 km and 44 % of that distance is covered with high velocity (>21 km / h). During match player has 94 high-intensity bursts on average. Defenders spend more time on ice, but they have less high intensity bursts compared to forwards. Most distance, about 75 %, covered on skates is done with velocities of 12 – 24 km / h (Keränen et al. 2020). Brocherie et al. (2018) got results of 22 shifts per match on average and average of 4,4 km of skating distance which is in line with Lignell (2017) study. Approximately half of the shift time was used for effective playing and half of the time when puck was out from the play.

From the year 1979 to year 2005 physiological characteristic of NHL players have changed. Size of player has increased in weight and height; anaerobic power and grip strength have increased. Absolute oxygen uptake has increased but relative oxygen uptake to body weight has not increased. (Keränen et al. 2020.) There are differences in some physical characteristics of players between different studies. In 2017 Chiarlitti et al. (2017) represented data of 37 collegiate professional ice hockey players. The average height of player was 182 cm whereas according to Laaksonen (2011) average height of NHL player was 188 cm in one study and 186 cm in another one. Weight of a professional player has been averaging on both sides of 90 kilograms. It seems that in NHL player size is bigger than in other professional leagues. Vigh-

Larsen et al. (2019) did large research about Danish ice hockey player anthropometrics and physiological performance. Their results are presented in tables 1 and 2.

TABLE 1. Anthropometrical charasteristics of players in Danish ice hockey players (Vigh-Larsen et al. 2019).

Table 1
Physical characteristics of elite and subelite ice hockey players and positional differences.*

	Elite (*n* = 145)	Subelite (*n* = 111)	Effect size	Forwards (*n* = 56)	Defensemen (*n* = 86)	Goalies (*n* = 19)
Age (y)	23.5 ± 4.4† (22.8–24.2)	19.4 ± 2.9 (18.8–20.0)	1.06, large difference	24.1 ± 4.5 (23.1–25.1)	22.7 ± 4.1 (21.6–23.8)	24.4 ± 24.4 (21.9–26.9)
Height (cm)	182.3 ± 5.2 (181.5–183.2)	180.9 ± 6.8 (179.6–182.2)	0.23, trivial difference	181.4 ± 4.2 (1,80.3–182.4)	183.6 ± 5.2 (182.2–185.0)	183.8 ± 7.0 (180.4–187.2)
Body mass (kg)	85.7 ± 8.1† (84.3–87.0)	80.8 ± 10.0 (78.9–82.7)	0.54, medium difference	85.1 ± 7.5 (83.5–86.7)	86.5 ± 9.1 (84.1–88.9)	86.8 ± 10.6 (81.7–91.9)
Body fat (%)	15.1 ± 4.0 (14.4–15.7)	15.6 ± 6.5 (14.4–16.8)	0.10, trivial difference	15.4 ± 4.2 (14.5–16.3)	14.6 ± 3.8 (13.6–15.6)	16.5 ± 3.6 (14.8–18.2)
Muscle (kg)	41.9 ± 3.9† (41.2–42.5)	38.8 ± 4.7 (37.9–39.7)	0.73, medium difference	41.6 ± 3.7 (40.8–42.4)	42.3 ± 4.3 (41.2–43.5)	41.4 ± 5.2 (38.9–43.9)

*Data are presented as mean ± *SD* and 95% confidence intervals. Goalies are excluded from comparisons between elite (*n* = 145) and subelite players (*n* = 111), whereas positional differences are compared within the elite level only (forwards *n* = 86; defensemen *n* = 56; and goalies *n* = 19).
†Significant difference between elite and subelite players, $p \leq 0.05$). Effect size is calculated and shown for differences between elite and subelite players.

TABLE 2. Physiological characteristics of players in Danish ice hockey players (Vigh-Larsen et al. 2019).

Table 2
Performance characteristics of elite and subelite ice hockey players and positional differences.*

	Elite (*n* = 145)	Subelite (*n* = 111)	Effect size	Forwards (*n* = 56)	Defensemen (*n* = 86)	Goalies (*n* = 19)
Countermovement jump (cm)	50.1 ± 6.1† (49.1–51.1)	44.9 ± 5.4 (43.8–45.9)	0.90, large difference	50.0 ± 5.3 (48.8–51.1)	50.4 ± 7.2 (48.5–52.4)	47.3 ± 4.0 (45.3–49.3)
5-10-5 pro agility (s)	4.76 ± 0.17† (4.73–4.79)	4.96 ± 0.22 (4.91–5.00)	1.05, large difference	4.75 ± 0.16 (4.71–4.78)	4.78 ± 0.17 (4.74–4.82)	N/A
Sprint 0–10.85 (s)	1.82 ± 0.10† (1.80–1.83)	1.9 ± 0.11 (1.88–1.92)	0.83, large difference	1.81 ± 0.10 (1.79–1.83)	1.82 ± 0.09 (1.80–1.85)	N/A
Sprint 10–33.15 (s)	2.65 ± 0.10† (2.62–2.66)	2.78 ± 0.12 (2.75–2.8)	1.17, large difference	2.64 ± 0.09 (2.62–2.66)	2.65 ± 0.11 (2.62–2.68)	N/A
Sprint total time (s)	4.49 ± 0.16† (4.46–4.51)	4.71 ± 0.19 (4.67–4.75)	1.28, large difference	4.48 ± 0.14 (4.45–4.51)	4.49 ± 0.18 (4.44–4.54)	N/A
Yo-Yo IR1-IH$_{SUB}$ (% HR$_{MAX}$)	79.7 ± 6.8† (78.6–80.9)	88.0 ± 5.4 (87.0–89.1)	1.33, large difference	79.6 ± 7.6 (77.9–81.3)	79.9 ± 5.8 (78.4–81.5)	N/A
Yo-Yo IR1-IH$_{MAX}$ (m)	2,434 ± 414† (2,364–2,503)	1,850 ± 499 (1755–1944)	1.29, large difference	2,470 ± 395 (2,383–2,558)	2,381 ± 445 (2,262–2,500)	N/A

*Data are presented as mean ± *SD* and 95% confidence intervals. Goalies are excluded from comparisons between elite (*n* = 145) and subelite players (*n* = 111), whereas positional differences are compared within the elite level only (forwards *n* = 86; defensemen *n* = 56; goalies *n* = 19).
†Significant difference between elite and subelite players, $p \leq 0.05$). Effect size is calculated and shown for differences between elite and subelite players.

From tables 1 and 2 we can see that ice hockey players are big but not exceptionally tall and they perform well in strength and power tests. Aerobic capacity is good but not at the same level as anaerobic power.

3 CHECKING IN ICE HOCKEY

Generally checking means defensive method to gain the possession of the puck from another player. Body checking is the most common method for that, but it is just one type of checking. Body checking is checking where player hits another player with body, usually shoulder or hip. That can be done to the boards or on ice. There are detailed rules what kind of checking is not allowed. (NHL 2020, IIHF 2019.) In body checking, the movement of checker and puck carrier are usually not to the same direction. (Hockey Canada 2021). Body checking is forbidden among women and youngest juniors. The age when body checking is allowed is not same everywhere, but for example in Finland among under 12-year-old players, body checking is forbidden. (Suomen jääkiekkoliitto 2020.)

Body checking drills. There are body checking drills for teams to practice checking and body contact. Most of them are so called angling checking which means skating to same direction and pushing opponent to wanted direction or to the boards. (Hockey Canada 2021, Tearse 2011) Body checks can be also trained off-ice (USA HOCKEY 2011). Body checking drills are especially important for juniors who are preparing themselves for rule change which allows body checking (Tearse 2011). Body checking in the corner of the rink towards boards with higher velocity is not part of these practices. (Hockey Canada 2021, Tearse 2011). In the following figure there is explanation of a drill which includes body checking (figure 3).

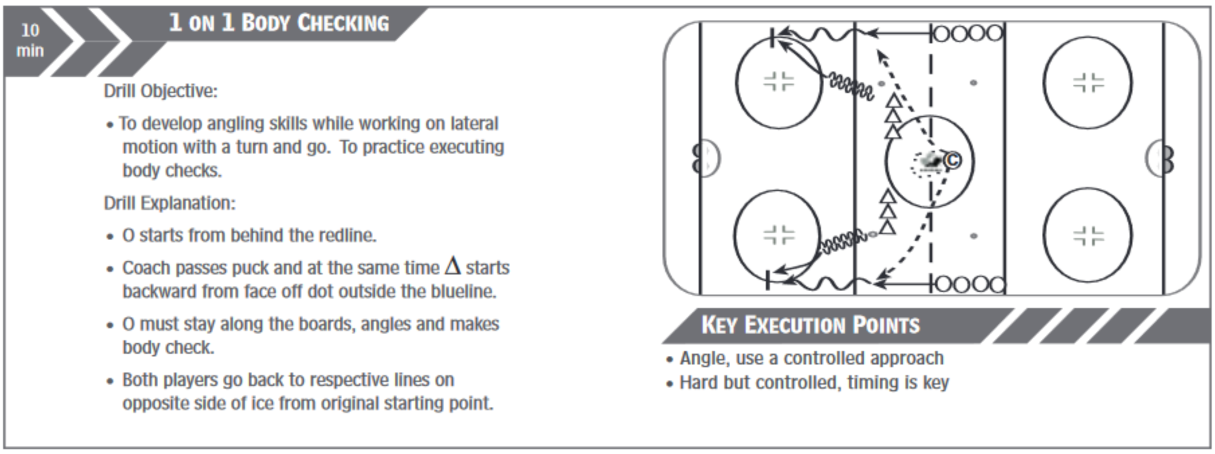

FIGURE 3. An example of drill including body checking (Hockey Canada 2021, modified).

3.1 Chceking rules

Checking must be done to a player who has possession of the puck, but there are many details what is not allowed to do. Bodycheck must be done with shoulder, body or hips and the contact must be from side or front. (IIHF 2019.) Referees do not control the game as strict as the rules state. Interpretation of rules is usually more permissive especially in situations where player actions don’t endanger player safety and there is already some contact between players (Rantala 2022). The most relevant checking rules are introduced here by listing what is forbidden and will end up as penalty:

-Checking from behind to vulnerable player who is not able to protect himself or aware of check.
-Checking to head or neck. If the check is delivered to head or neck, it is always illegal.
-Boarding, which means type of checking which causes opponent to be thrown violently towards boards.
-Charging, which means use of unnecessary force or jumping towards opponent.
-Elbowing. Use of elbow to foul an opponent.
-Cross-checking which means check that has been delivered with both hands on stick and stick not touching ice.
-Holding opponent or his stick and preventing him to from skating freely.
-Hooking, which means the use of the stick to interfere opponent from moving.
-Interference, which means obstructing player without the puck to from skating freely.
-Roughing, which mean jostling or striking opponent.

Besides them there are various ways defined how use of stick, such as high-sticking or tripping, can be penalized. (IIHF 2019.)

3.2 Body checking

Body checking, sometimes known as checking, is the most famous checking style. (Suomen jääkiekkoliitto 2020.) Body checking is often reason for injury and there have been modifications in rules to reduce injuries (LaPrade 2014, Flik et al. 2005, Biasca et al 2002). Still there are lot of injuries happening related to body checks (Tuominen et al 2017a, Aguiar et al 2020). Injuries are not the only interesting part in body checking because it is effective way to gain possession of the puck and that way is helping team to win (Pohjanvirta 2021).

Velocities what players experience during match are high. Typical skating velocity is 12 – 18 km/h but velocities which exceed 20 km/h are very common and sometimes even 30 km/h. (Keränen et al. 2020, Brocherie et al. 2018.) When playing velocities are high, it can be expected that some contacts happen also with high velocities. Bjering (2019) estimated checking velocities from videos. The accuracy of her method was not comparable with normal video analysis, but the research is providing detailed body checking velocities. Body checks which had outcome of concussion had mean velocities of 6.55 m/s for checking player and 4.59 m/s for injured player who received the check. There was no significant difference in velocities for checks which did not end up to concussion. To simulate contact to the boards Poutiainen et al. (2014) used velocities of 1.33 to 3.37 m/s. They defined those values from measurements during matches when measuring body checking velocities towards the boards.

There are some points that a player can do for better safety when being under a body check. The most important thing is to acknowledge the situation. Unanticipated body collisions result in higher linear and rotational head accelerations. Heavy impacts seem to be dangerous no matter of level of anticipation. Skating through the collision has been taught to players for better safety and checking. Keeping head up, and feet shoulder width apart are also ways for safer checking. (Mihalik et al. 2010.)

3.3 Measuring impacts

Impacts to head have been researched. Especially situations like shoulder, elbow and hand hitting head and defining head accelerations and effective mass of the hitting part. (Rousseau & Hoshizaki 2015, Potvin et al. 2019.) When observing the effective mass, Rousseau & Hoshizaki (2015) found out that impact with shoulder has the greatest effective mass, 12.9 kg. Comparison between tucked, 3.0 kg, and extended elbow, 4.8 kg, showed higher effective mass for extended elbow which was surprising. According to Potvin et al. (2019) impacts with hand give the highest peak acceleration to head, 20.35 g, and elbow give higher peak acceleration, 14.23 g, than shoulder hit, 10.55 g. Peak accelerations follow the same order in linear and rotational values. However, duration of the accelerative impulse was the greatest in shoulder hits, 2.1 times greater than in elbow hit and 2.5 times greater than in hand hit.

There has been some research on boards to find out which kind of rink boards are safer for players. Especially peak forces and stiffness of boards have been studied. (Poutiainen 2012, Marino & Potvin 2002, Schmitt et al. 2018.) Poutiainen (2012) reported peak force values which were from approximately 2000 N to 7000 N in simulated collisions with boards depending on colliding velocities, board system and straight or corner part of rink. New flexible boards gave smaller peak forces. Also, stiffness was smaller in new flexible boards. Marino & Potvin (2002) got same outcome in their research that old reference boards are stiffer and probably not so safe for players. Schmitt et al. (2018) measured effective mass of boards. They used velocity of 4.76 m/s^2. For the reference board the effective mass was 151.0 kg and for most flexible boards it was 60 – 61 kg. The effect of lower injury risks with flexible boards can be seen in studies. Especially number of shoulder and head injuries have decreased in tournaments which have had flexible board systems. (Tuominen et al. 2015, Tuominen et al. 2017a, Tuominen et al. 2017b.)

Videos have been often source for analysis in ice hockey impacts. They often lack detailed accelerations or forces of body parts. Usually, detailed accelerations would be interesting to know from head. (Hutchison et al. 2013.) Helmet-based accelerometers have been used to define more precise accelerations of head (Wilcox et al. 2014, Mihalik et al. 2010). When using accelerometer-based data in helmets, possible errors should be considered. Even though correlation between accelerometer and gyroscope systems to reference systems is strong, it is not as accurate as anthropometric test device. (Allison et al. 2013, Allison et al. 2015.)

4 INJURIES IN ICE HOCKEY

Ice hockey is known to be one of sports which has high risk for injury. Especially traumatic brain injuries are more common in ice hockey than in other team sports (Cusimano et al. 2013, LaPrade et al 2014.) High incidence of injuries is seen also in women's ice hockey even though body checking is not allowed in their rules. Even risk of concussion seems to be same between men and women. Injuries happen much more often in games than in practices among all groups. (Lynall et al 2018, Flik et al 2005 Renton et al. 2019.)

In junior world championships between 2006 and 2015 the distribution of injuries is following. Head or face 39 %, upper body 29 %, lower body 24 %, spine or trunk 9 %. (Tuominen et al. 2017a.) Flik et al. (2005) analyzed anatomical distribution of injuries in ice hockey as well and their results are presented in the figure 4.

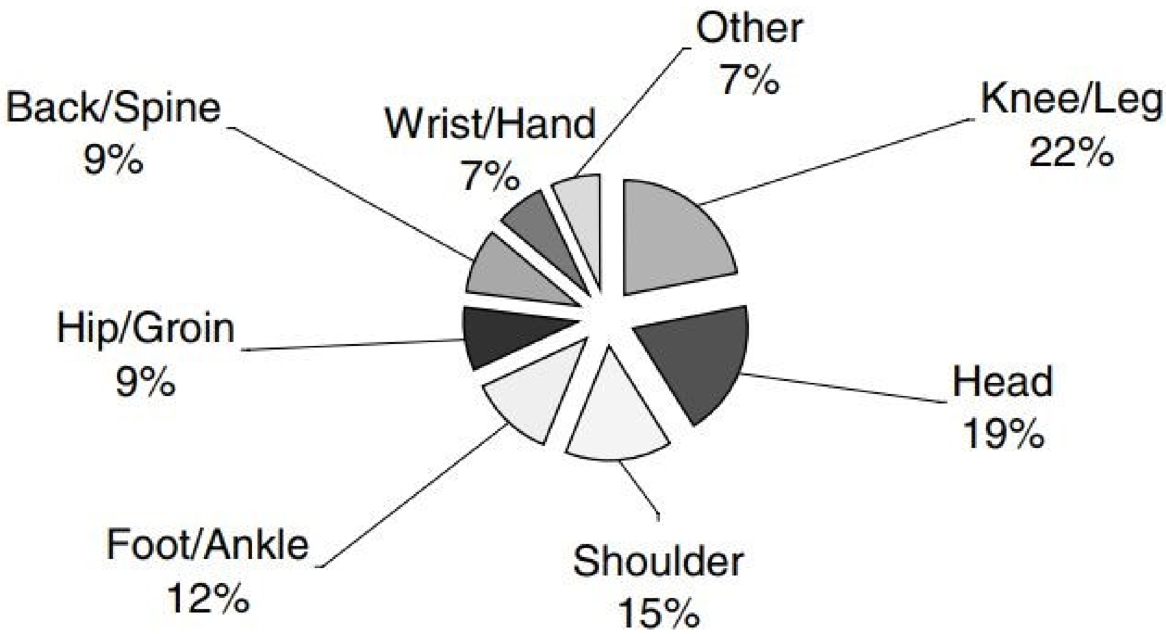

FIGURE 4. Anatomical places for injuries in ice hockey (Flik et al. 2005).

When looked at in what kind of situation the injury has happened; collision with opponent is the most common situation (Flik et at. 2005, Tuominen et al. 2017, Lynall et al. 2018). Next graphics presents causes of injuries (figure 5).

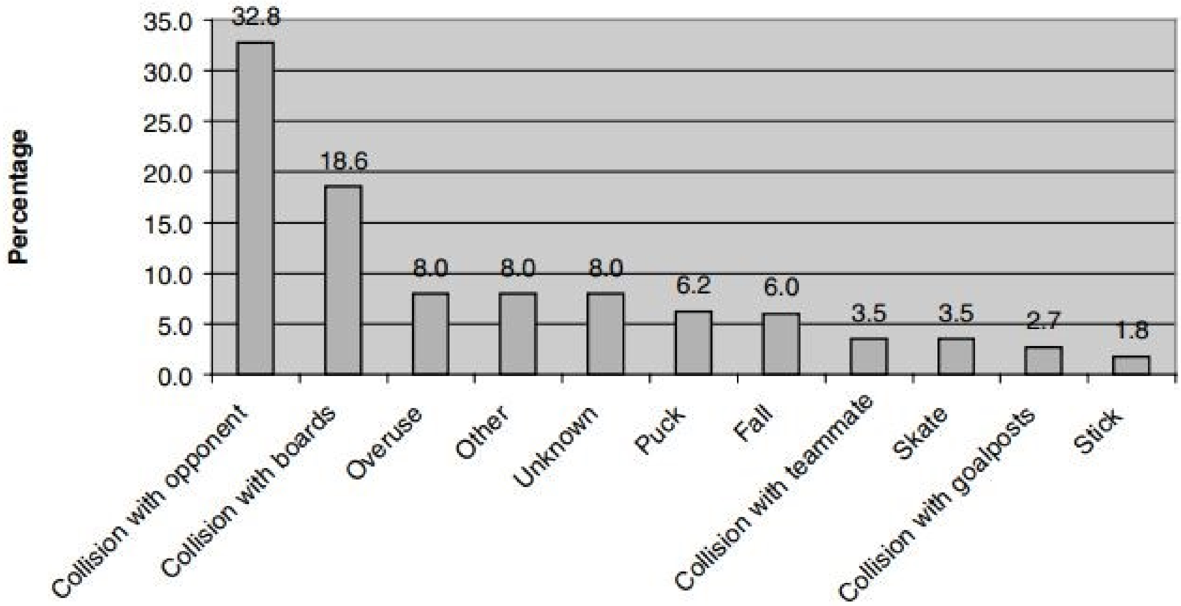

FIGURE 5. Causes for injuries (Flik et al. 2005).

From the figure 5 it is clear that contacts with other players are the biggest reasons for injuries. Also, board contact is clearly taking some attention. Tuominen et al. (2017a) and Lynall et al. (2018) got similar results with causes for injuries. Injuries happen much more often in matches than in practices (Flik et al. 2005, Lynall et al. 2018).

4.1 Concussions and head impacts in ice hockey

Concussions are often under extra surveillance in ice hockey because of their high incidence but also because of the severity of the injury (Tuominen et al. 2017b, Renton et al. 2019, Biasca et al. 2002). Severity of head impacts is not based only in concussions, because repeated head impacts can lead to neurological consequences (Karton & Hoshizaki 2018). In the history there has been many new rules and protective equipment implemented to lower injury risk. Despite of them, severity and incidence of ice hockey injuries have increased from 1960s to 2000. To lower the injury risk, protective equipment should be worn correctly and careless play against rules should be minimized. (Biasca et al. 2002) It can be so, that protective equipment increases more reckless play which takes out the possible decrease in rate of injuries. Number of catastrophic injuries have decreased even though total amount of injuries have not. (Daneshvar et al. 2011.)

According to Wilcox et al. (2014) an individual player has a head impact of magnitude over 20 g in every 2 or 3 games in men's ice hockey. 50 % of them were consequences from contact with another player. Concussions occur in much smaller rate. Tuominen et al. (2017b) studied concussions in many ice hockey tournaments. The average incidence rate for individual player was 1.1 concussions for 1000 games. The number of concussions seemed to be decreasing during the study period. Reasons for that were probably more flexible board glass and stricter rules. Especially the number of concussions related to board contact decreased drastically when game was played with flexible boards. Pfister et al. (2016) show similar results to concussion risk in ice hockey. Their incidence rate value was 1.2. There was only one sport with higher incidence rate which was rugby with incidence of 4.18. American football had incidence rate of 0.53.

Head impacts happen often at boards; usually in contact with board (60.8 %) and sometimes just next to board. Open ice accounted for 11.6 % cases and at goal 12.5 % of all cases. 36 % of cases happened without puck possession and most of cases just at the moment of getting or releasing the puck. Approximately half of the impacts happen in the offensive zone. They also found out that half of impacts happen without looking at the direction of collision. (Aguiar et al. 2020.) Even though most head impacts happen at the boards, most of concussions seems to happen open-ice nowadays (Tuominen et al. 2017b). Wilcox et al. (2014) got results that contact with opponent is the most common reason for head impact. The limiting value was there 20 g for a head impact and body contact was the reason in 50 % of cases. Board was the reason for 31.1 % among men and 17.3 % among women. For women indirect contact was reason in 15.3 % of cases when it was only 4.4 % in men. Even celebrating accounted for small part of head impacts. The highest average head acceleration values, linear and rotational, came from contacts with ice in both men and women. Among men it was average of 40.1 g and when contact with other player average value was 28.0 g. Average rotational accelerations were from 2056 to 3454 rad/s^2.

According to Mihalik et al. (2010) open-ice collisions resulted in higher linear and rotational accelerations in head. Collisions which were not anticipated increased the accelerations of head. 66 % of concussions in junior world championships were result from illegal body contact. The trend of relative number of illegal contacts in concussions was decreasing from 2006 to 2015. (Tuominen et al. 2017b.) The most common type of contact was initial contact from shoulder to head which accounted for 42 % of concussions in NHL. In most cases contact was to lateral side of the head. (Hutchison et al. 2013.)

Zhang et al. (2004) defined some values for head accelerations which have risk for brain injury. For linear accelerations, values of 82 g have 50 % risk for brain injury. For rotational acceleration values of 5900 rad/s^2 has the same 50 % risk for brain injury. From data that shows only total force or acceleration that head undergoes, it is not enough to tell the load of the impact. There is so called head impact criterion (HIC) which is telling more about the severity of the impact when durations of accelerations are observed as well. There is still problem in the HIC values if it does not take rotational accelerations into account. (Ji et al. 2014.)

4.2 Other injuries in ice hockey

Past 30 years there has been much research on injury incidence in ice hockey (Lorentzon et al. 1988, Mölsä et al. 1997, Flik et al. 2005, Tuominen et al. 2015). Injury is most likely something else than concussion, which can be seen also from the figure 6. Even though concussions have been in some studies the most common injury type. (Flik et al. 2005.) Lacerations have been reported to be the most common one before contusions and sprains (Tuominen et al. 2015, Tuominen et al. 2017a). Internal derangement of knee has been reported to be the most common injury type in one study (Agel et al. 2007). In Lorentzon et al. (1988) study distinctly the most common injury type was contusion. They described injury as such injury which causes player to skip next training or match. Lacerations and concussions were in the list with the smallest incidences. If absence of next event was not counted, would number of lacerations be on the top of the list with minor injuries. So, it is clear that there are many types of injuries which can occur in ice hockey and injury types and reporting have probably changed during past decades.

Typical injuries in lower extremity are knee medial collateral ligament sprains and high ankle sprains (Flik et al 2005, LaPrade 2014). Hip is also common site for lower extremity injury (Lynall et al. 2018). For upper body, shoulder is the most common injury position. Number of shoulder injuries has decreased in the last years in consequence of flexible boards. (Tuominen et al. 2017a.) Precise injuries in shoulders are often acromioclavicular joint separations, clavicle fractures and glenohumeral dislocations (LaPrade et al. 2014). More than half of shoulder injuries are reported to originate from board contacts (Tuominen et al. 2015). Many studies show that checking is usually the most common cause for injury and after that there are stick on the second place and puck often on third place (Mölsä et al. 1997, Tuominen et al. 2015, Tuominen et al. 2017a). Injury that is caused by stick is usually laceration in face or injury in hand or wrist (Tuominen et al. 2015).

Tuominen et al. (2015) reported injury incidence of 52.1/1000 player-game hours. It is in line with previous studies which had incidence from 36 to 78.4 injuries/1000 player-game hours (Lorentzon et al. 1988, Mölsä et al. 1997). Studies which have compared injury rates between practices and games point out that there is many, usually over 10 times, higher risk for injury in games. (Tuominen et al. 2015, Mölsä et al. 1997, Lorentzon et al. 1988). Most of injuries result in less than one week absence from training but approximately 15 % did not return to play in 3 weeks (Lynall et al. 2018, Tuominen et al. 2015). From common injuries, high ankle sprains end up taking the biggest time away from playing. They can take up to 12 weeks to recover well enough to play. Even though some knee injuries, such as torn anterior cruciate ligament, keeps player away from playing very long time, it is not common injury in ice hockey. Medial collateral ligament (MCL) injury does not take more than 8 weeks in most of cases. From type 1 MCL injuries return to play takes under 2 weeks. (LaPrade et al. 2014, Mosenthal et al. 2017.)

5 RESEARCH QUESTIONS

Ice hockey dasher boards have changed to more flexible ones in the past years. Better flexibility should be safer for players and smaller injury rates have been observed. (Poutiainen et al. 2014, Tuominen et al. 2015, Tuominen et al. 2017a, Tuominen et al. 2017b.) Playing velocities are high nowadays in elite leagues (Keränen et al. 2020, Lignell et al. 2017). And there is assumption that body checking velocities could be higher because of flexible boards. The aim of this study is to find out checking velocities towards boards between different age groups and observe board behaviour and head acceleration of players. The research questions of this study were:

1) What are velocities in body checking towards the boards?

Hypothesis was that among Liiga players velocities were expected to be same or higher than in study of Poutiainen et al. (2014) for sandfilled bag, which was 3,37 m/s. Because older players are stronger, faster and are used to body checks, velocities were expected to be little bit smaller in junior groups than in Liiga group, but the difference would be small.

2) How is the board behaving in real checking situation?

Board is expected to show higher stopping distances for older and heavier players, from both, element and glass part. The reason for that is in greater mass in older players and they might have higher velocities as well.

3) What kind of head accelerations happen in checking?

Head accelerations were hypothesized to be lower than 20 g which is value that doesn’t happen in every match for professional ice hockey player. It was hypothesized that juniors would have higher peak head acceleration values due to lesser board displacement.

6 METHODS

Measurements consisted of body checking drill and body checks from official matches. All measurements were done in autumn 2021. Body checking drills with six different groups were done in October and seven matches were filmed in November. Each body checking drill group performed at least 18 body checks.

6.1 Subjects

Subjects for the simulated body checking drills were all from competitive teams. Liiga is the highest level in Finland and junior teams play also matches regularly. For example U20 means that players in that group must be younger than 20 years. Groups were: Liiga, U20, U18, U16, U15 and U14. In one group there were from six to eight players which means that every player body checked and was checked at least three times. In younger groups players were asked to check and be checked 4 times that failed checks can be left out. Table 3 shows anthropometric values of each group.

TABLE 3. Average weight and height of players. Values were not measured but asked the estimation of own weight and height from each player.

	U14 (N=7)	**U15** (N=7)	**U16** (N=8)	**U18** (N=6)	**U20** (N=6)	**Liiga** (N=6)
weight (kg)	54,43 ± 4,17	65,86 ± 9,79	66,63 ± 4,55	72,83 ± 5,76	84,23 ± 4,34	87 ± 8,08
height (cm)	166,57 ± 3,50	176,71 ± 4,40	176,13 ± 3,72	179,17 ± 3,62	183,5 ± 4,92	182,17 ± 2,54

The match measurements were done from four adult matches, which were 2 Liiga and 2 Suomi-sarja (3rd highest level in Finland) matches. Three junior matches were also filmed which were two U20 matches and one U18 match.

6.2 Measurement setup

Every body check was filmed by three cameras and two to three accelerometers. Accelerometers (MMA2301, Freescale Semiconductor Inc, USA) were attached to the board to measure board acceleration during impacts with collection frequency of 1000 Hz and accuracy of ± 0.006 g. One accelerometer was at element part 7 cm below the glass, second accelerometer was placed 66 cm above rail to glass part of the board to be approximately at the height of head of an adult ice hockey player. Third accelerometer was attached 30 cm above the rail to express height of head of a junior ice hockey player. Accelerometers were equipped with colourful tape so, that from video behaviour of the board at the place of accelerometers can be analyzed Accelerometer and board marker setup is visible in the figure 6.

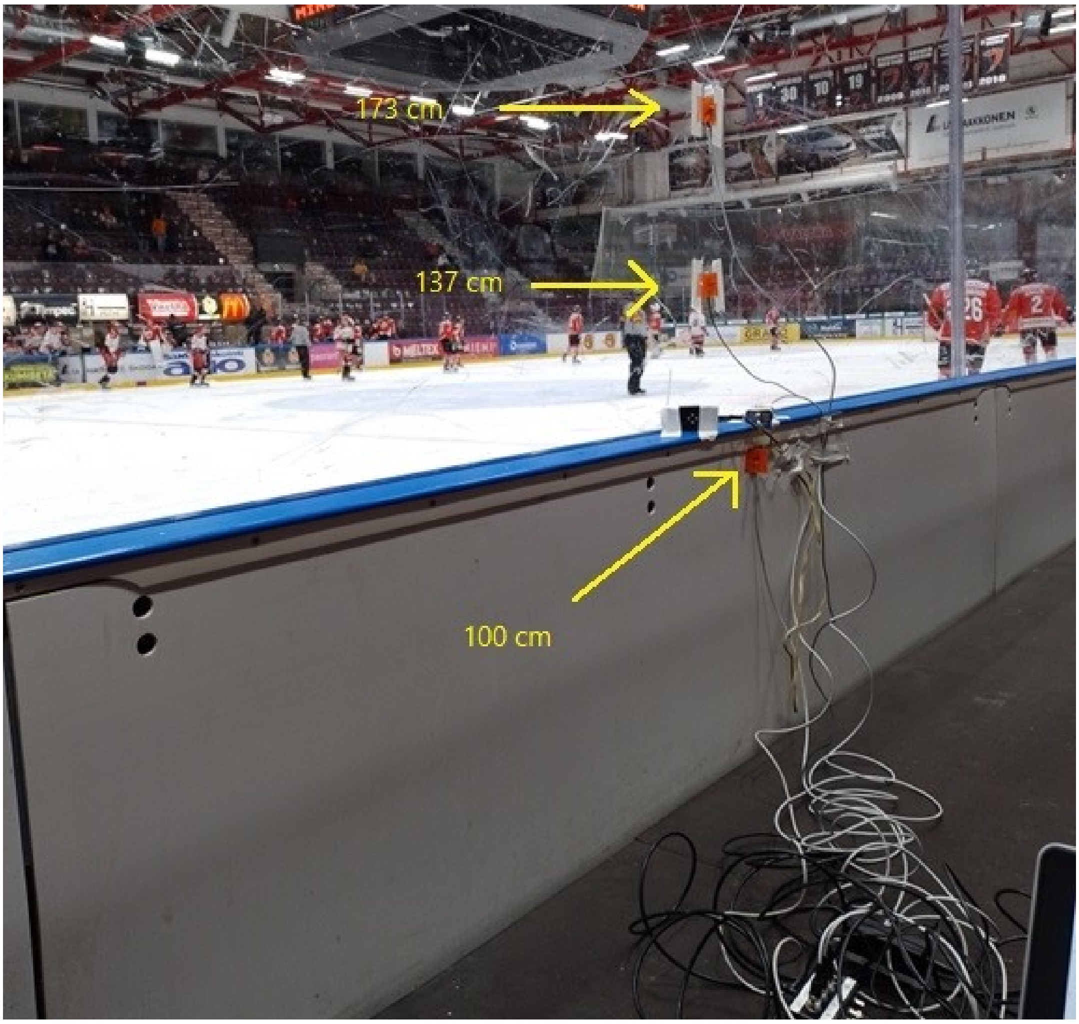

FIGURE 6. Picture of marker and accelerometer setup from Suomi-sarja match. Values represent heights of marker and accelerometer positions above ice level.

Two cameras were placed to film players' heads. Cameras were Sony RX 100 M2 and M3. They recorded at 250 fps with shutter speed of 1/1000s, aperture was f/4.0 and ISO value 3200. Video resolution was 1920 x 1080 and one pixel accounted for 3,4 mm on average. Post trigger was used. Third camera was Sony RX 100 M6. That recorded board behaviour from almost perpendicular to the board. That camera had also post trigger and fps was 250. Shutter speed was 1/1000 s., aperture was f/4.0 and ISO value 2000. Video resolution was 1920 x 1080 and one pixel accounted for 1,9 mm. Synchronizing light was triggered during a body check for 3D-video analysis. Players had a marker attached to on top of their helmets. Because of different helmets and different people for placing the marker, the exact spot of the marker varied some centimeters between players. Figure 7 shows the marker placement to a helmet.

FIGURE 7. Picture of the marker that is attached to a player's helmet (Photograph by Tuomo Hyvärinen).

In Liiga matches accelerometers were left out and camera settings were changed that two cameras which focused on players' heads filmed with continuous 100 fps because of different camera placement and inability to trigger cameras in exact moment because of crowded arena.

6.3 Measurement protocol

Body checking drill was done like in the figure 8. Puck holder (player who receives the body check) started from the red line to skate with puck parallel to boards. Defender (player who body checks) started at the blue line to go around the cone and body check at the designated part of the board which was marked with tapes. Both players skated forwards. All groups were instructed to body check safely and according to rules but as close to match situation as possible. Each execution started from blow to a whistle.

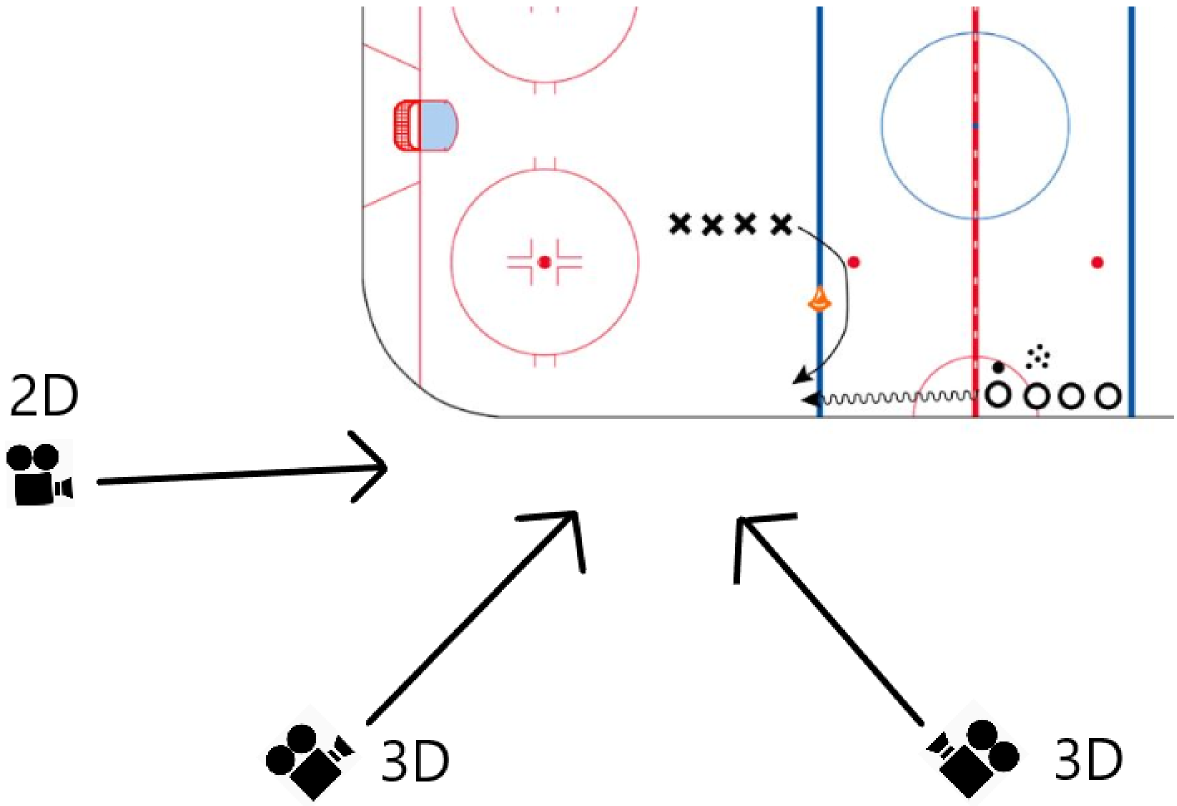

FIGURE 8. Drawn version of the drill and camera placement. 3D cameras were there to follow players and 2D to follow the board (Modified from drawing by Aku Nieminen, Vierumäki).

Simulated body checks for groups U18 to U14 were done under supervision of their coach. The coach had the possibility to teach players and give feedback from their performances. Some coaches gave more feedback, and someone only followed. Especially in U18 group the coach gave more instructions whereas in U14 group the coach only observed. Players' comments to question about how body checks felt and how it was compared to match situation, answers were usually that it was quite close to match situation but in match body checks would have been little bit harder. Figures 9 and 10 show how the drill looked like from ice.

FIGURE 9. Starting positions for the drill (Photograph by Tuomo Hyvärinen).

FIGURE 10. Example of one check (Photograph by Tuomo Hyvärinen).

Matches that were filmed were from same groups and the same rink as the simulated body chekcs. Therefore, groups: Liiga, U20 and U18 were chosen. Younger juniors did not have matches at the same rink. Initial target was to film at least two matches from each group. Two Liiga matches were filmed but there didn't occur many body checks in the measurement area. Two Suomi-Sarja matches filmed in addition to Liiga matches from the group of adults. Two U20 matches and one U18 match was recorded succesfully. The setup was the same for matches as for drills except for Liiga matches. Whenever body check happened in the wanted area, cameras were post triggered to record the body check.

6.4 Data analysis

Videos were digitized with digitizing program (https://github.com/tjrantal/javadigitiser). From players, only marker on top of their helmet was digitized. Board markers were digitized with the same program. 3D coordinates and metric values were computed with Matlab-software

(MathWorks MATLAB R2020b) and those values were analyzed with Excel (Microsoft Office 365 Excel version 2206). Raw data was filtered with 4^{th} order zero-phase shift butterworth low-pass filter with cut-off frequency of 12.

Player speed and velocities represent values at the time of contact. That was determined by the moment of a shoulder of defender touching to puck holder. In case the shoulder was not responsible for big initial contact, then contact moment was determined when other body part generated relatively big effective mass to the opponent. Usually from torso or hips for example. Board stopping distances were calculated from the difference between pre contact position difference to maximal displacement of the board. Only body checks which occurred at the correct frame of the rink were analyzed.

Some body checks were left out from analysis because of failed execution of the check. Such as clear miss or missing the correct board where to body check. In the analysis phase some body checks ended up being performed in a way that the head of the checking player couldn't be digitized after contact. Then maximal head acceleration value was not calculated but only velocity at the time of contact. Everything that was possible to measure trustworthy, was included to the analysis. Usually that meant that head acceleration value of the checking player was sometimes left out. Digitizing at the time of contact was too unsure sometimes, that all values of the checking player were left out. If the body check was a miss, then none of the measured values was analyzed. There were in total 139 trials in body checking drill and 120 were analyzed and 103 of them included all values.

Averages from different groups will get the most attention but the top three biggest hits from each group will be gone through as well. Those 3 biggest hits were chosen by the highest peak head acceleration values of the puck holder. All match measurements were analyzed as a one group because there were so few body checks in the filming area. In total nine body checks were taken to analyzing part and only three of them hit the wanted board frame.

Board displacement, or in other words stopping distance, was observed from three different parts. Those parts were upper part of the element, glass at height of 30 cm from element and glass at height of 66 cm from element. Glass 30 cm was missing from Liiga and U20. Figure 11 shows that differences between 30 cm and 66 cm were so small that 66 cm can be used for analysis and leave 30 cm part away from most analysis.

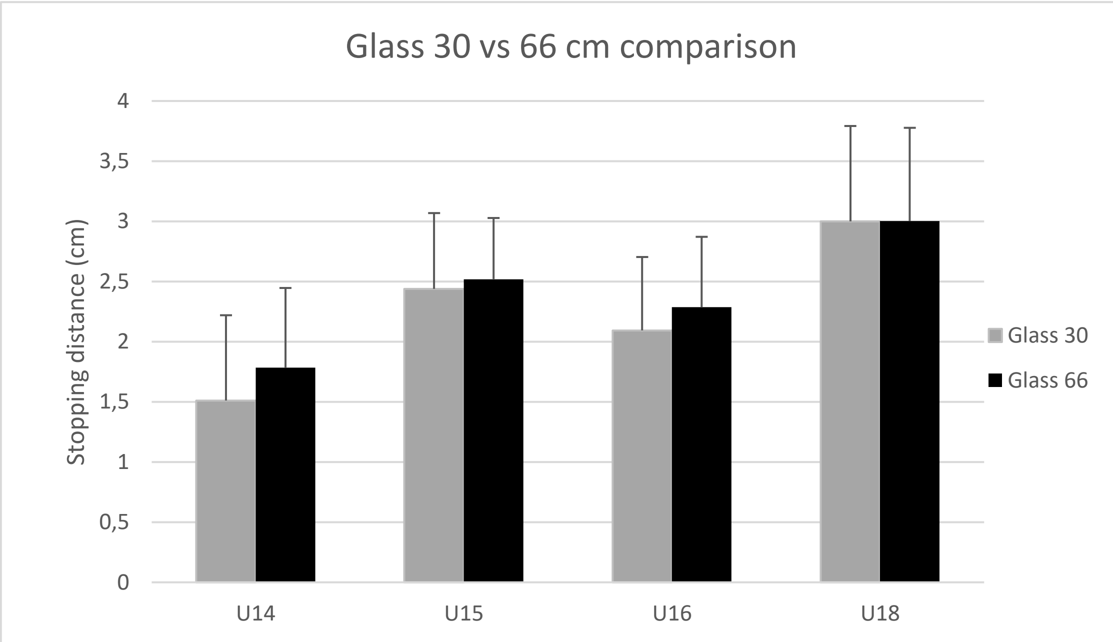

FIGURE 11. Comparison of 30 and 66 cm glass stopping distances.

Accelerometer data was analyzed with Signal-software (Signal version 4.11, Cambridge Electronic Design, Cambridge UK). The data was not interesting for research questions, and it was too unreliable to predict the magnitude of a body check. In the figure 12 two trials are visible which gave very different maximal acceleration values even though the stopping distances were similar.

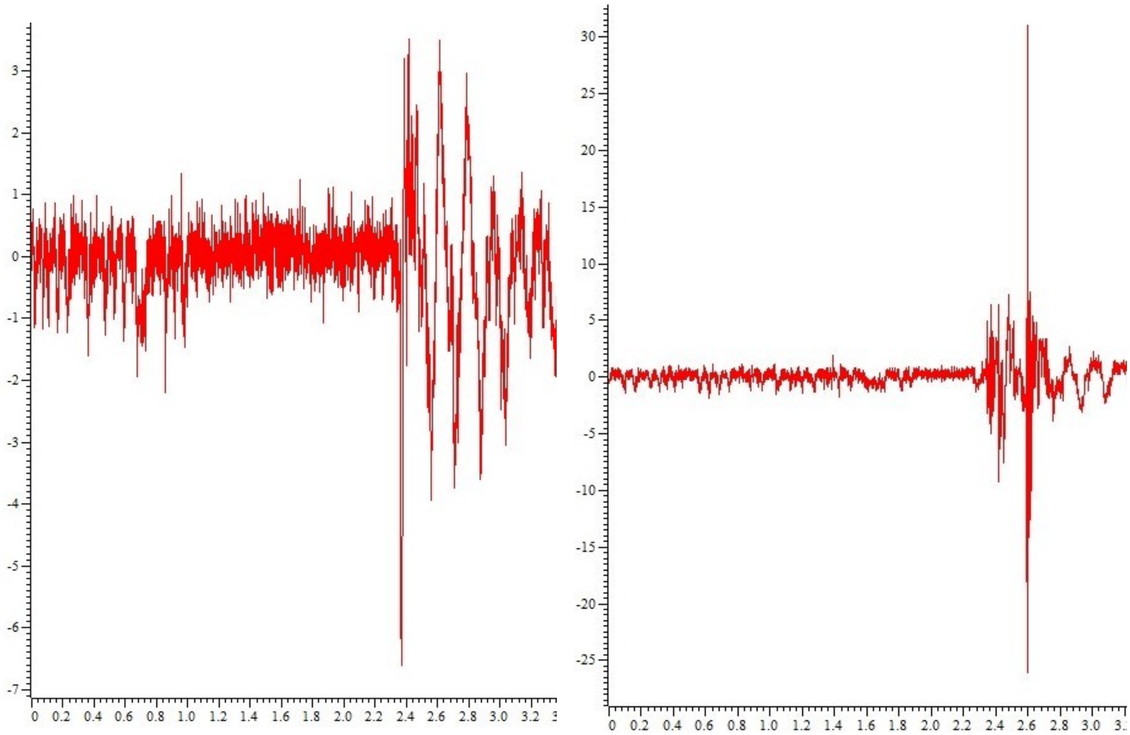

FIGURE 12. Examples from accelerometer data from U18 group. Negative values represent acceleration away from ice. High peaks on the right-hand side graph are due to stick hitting the glass. Notice different Y-axis scale.

6.5 Statistical analysis

Group averages and standard deviations were calculated with Microsoft Excel. SPSS-software (IBM SPSS Statistic 26) was used for analysing statistical significances. Statistical significances were analysed from following variables: Defender speed and perpendicular velocity, peak head accelerations and board behaviour. Differences were compared to Liiga group. Exceptions were in head accelerations where comparisons were done between all groups. Test that was used is independent sample Kruskal-Wallis test. Statistical significance limit was set to 0.05.

7 RESULTS

7.1 Player velocities

Table 4 shows player velocities between different groups. Speeds varied from about 4 m/s to 6 m/s which is 14,4 km/h to 21,6 km/h. Puck holder was skating mostly parallel to boards while defender had significant perpendicular velocity. Defenders' angle of arrival was approximately 30° to 45° in body checking drill, while in matches body checks were done with more perpendicular approach.

TABLE 4. Players' velocities and defenders' angle of arrival.

Variable	U14	U15	U16	U18	U20	Liiga	Matches
Defender speed (m/s)	4,28 ± 0,52	4,41 ± 0,61	4,97 ± 0,57	5,29 ± 0,72	5,25 ± 0,61	5,47 ± 0,58	4,82 ± 0,77
Defender perpendicular velocity (m/s)	2,79 ± 0,57	2,66 ± 0,49	2,88 ± 0,46	3,50 ± 0,65	2,66 ± 0,52	3,22 ± 0,26	3,73 ± 0,69
Puck holder speed (m/s)	4,35 ± 0,53	5,10 ± 0,57	5,36 ± 0,55	6,15 ± 0,34	5,30 ± 0,49	5,27 ± 0,58	4,42 ± 2,22
Puck holder perpendicular velocity (m/s)	0,60 ± 0,40	0,87 ± 0,48	0,87 ± 0,39	0,95 ± 0,44	0,63 ± 0,32	0,68 ± 0,41	1,08 ± 0,51
Defender angle of arrival (°)	42,39 ± 12,26	38,07 ± 9,03	33,91 ± 9,06	41,38 ± 4,54	30,86 ± 5,90	36,53 ± 4,14	54,03 ± 14,18

Puck holder speed and perpendicular velocity were quite similar between different groups with some exceptions. The youngest group, U14, showed smallest velocities and U18 highest. Bigger differences were in defender speed and velocities. Defender was responsible for executing the body check whereas puck holder was just skating and preparing for the check. Among defenders, the youngest groups, U14 to U16, speed and perpendicular velocities were statistically significantly smaller ($p<0.05$) than in Liiga group. Big deviations in match cases were expected compared to more controlled checking drill situation. Figure 13 shows defender velocities and Figure 14 shows puck holder velocities.

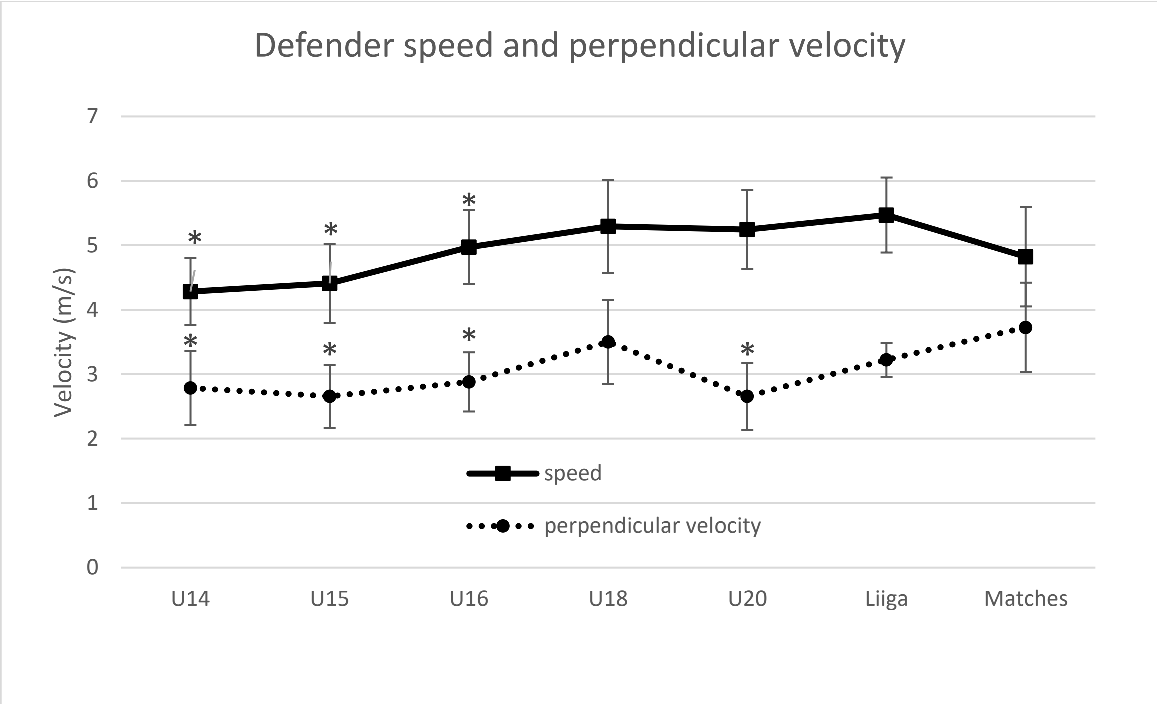

FIGURE 13. Defender speed and perpendicular velocity in body checking drills and in matches. * shows statistical significance (p<0.05) between group in question and Liiga group.

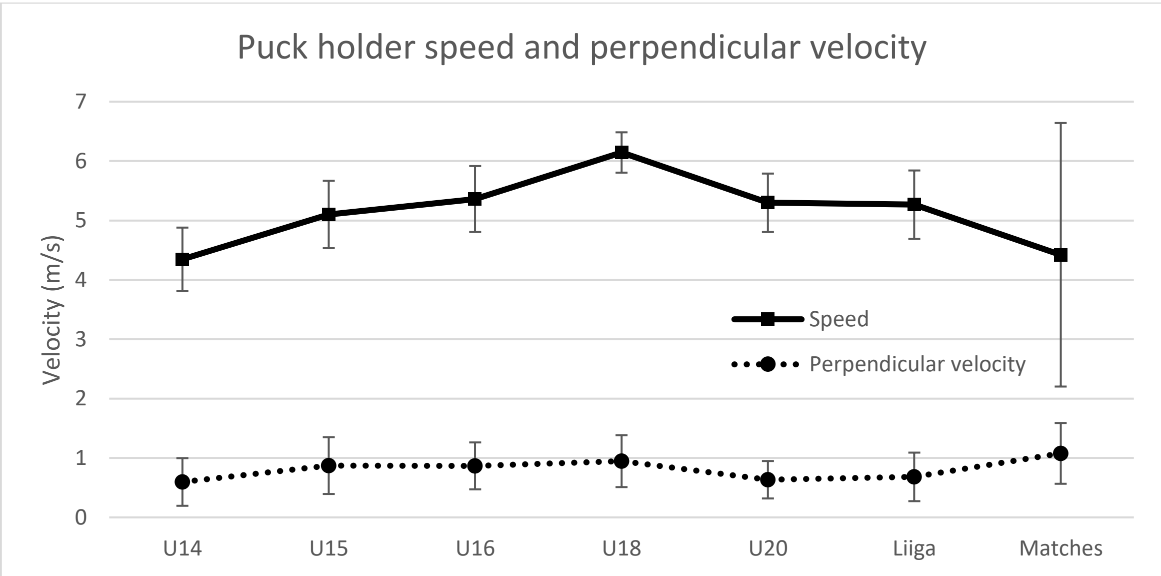

FIGURE 14. Puck holder speed and perpendicular velocity in body checking drills and in matches.

Figure 15 shows that in body checks which cause higher accelerations to the puck holder, defender's velocity towards boards is greater in all groups.

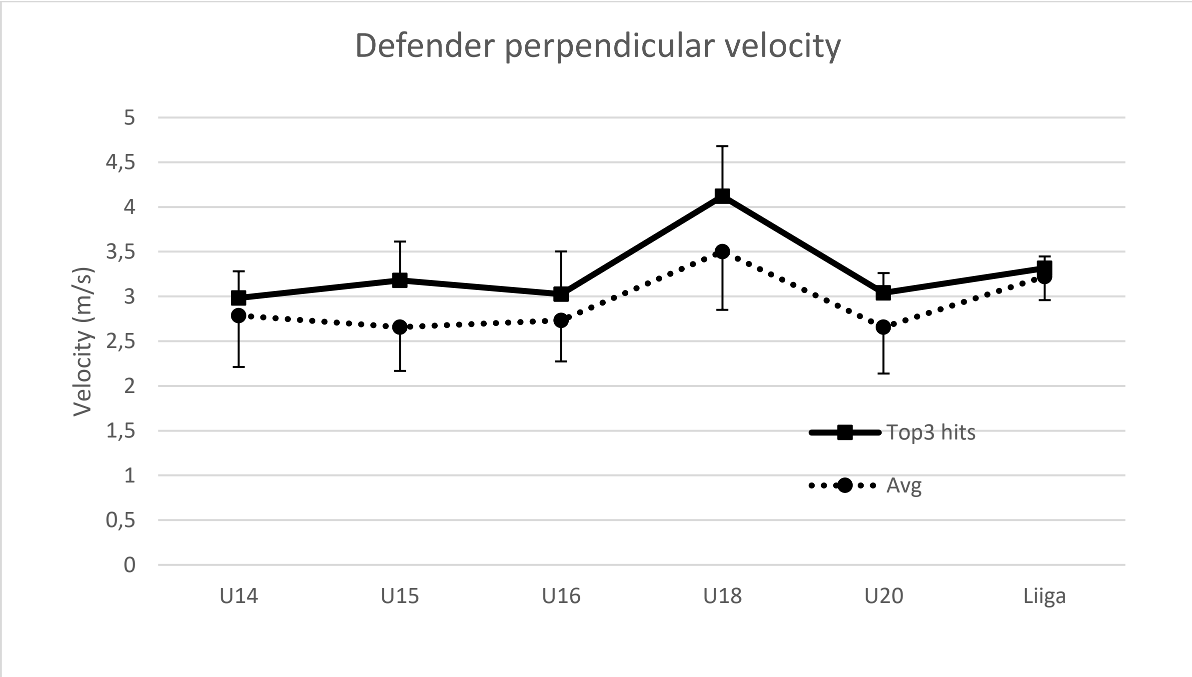

FIGURE 15. Defender's perpendicular velocities. Group averages and averages from top 3 biggest hits.

7.2 Head accelerations

Peak head acceleration values didn't vary much between different groups. Puck holder accelerations differences between groups were so small that there were not statistically significant differences. Defender's highest values were in U18 group. Figure 16 shows values graphically. U14 and U20 had statistically significantly lower ($p<0.05$) peak values compared to U18 and to Liiga groups. U15 had statistically significantly lower ($p<0.05$) peak values compared to U18, but not to Liiga.

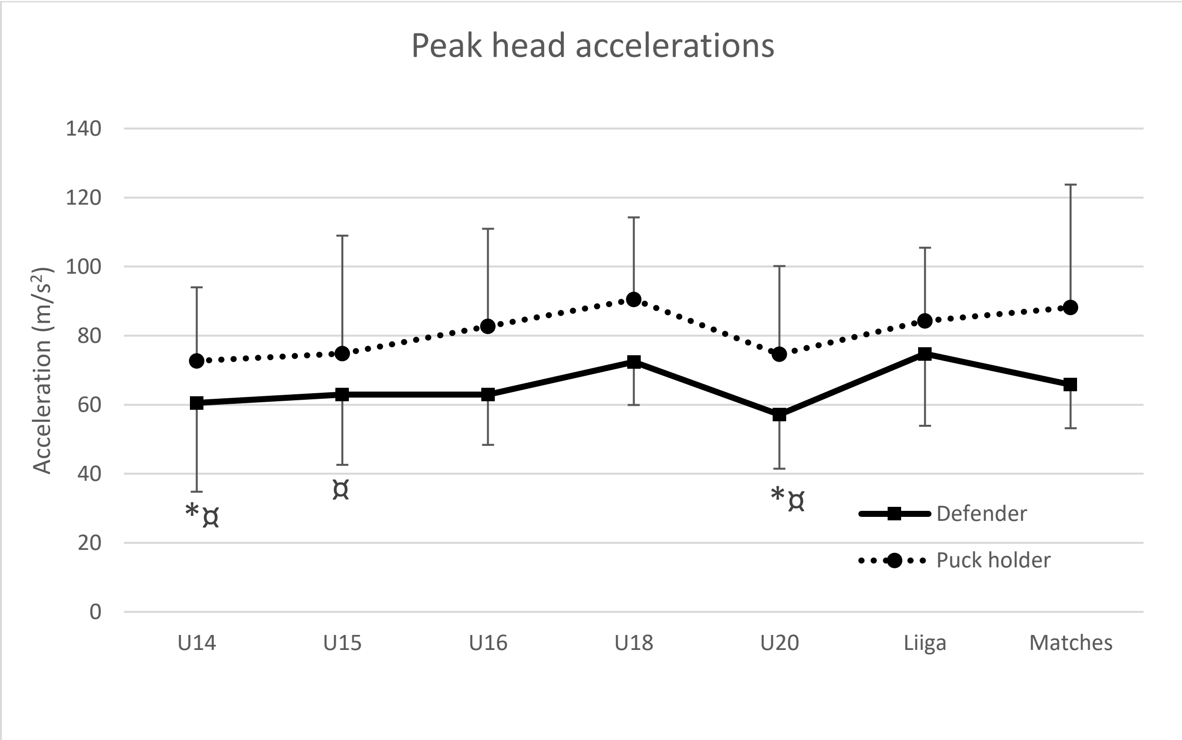

FIGURE 16. Peak head accelerations. * shows statistical significance to Liiga group and ¤ shows statistical signifance to U18 group ($p < 0.05$).

In all groups on average puck holder had higher head accelerations compared to defender. Deviation was quite big in all groups and especially among puck holders. It caused that statistically significant differences were not seen except between very few groups. When on average highest values were in U18 and Liiga groups, in top 3 biggest hits U15 group is having the lead. This can be seen in the figure 17.

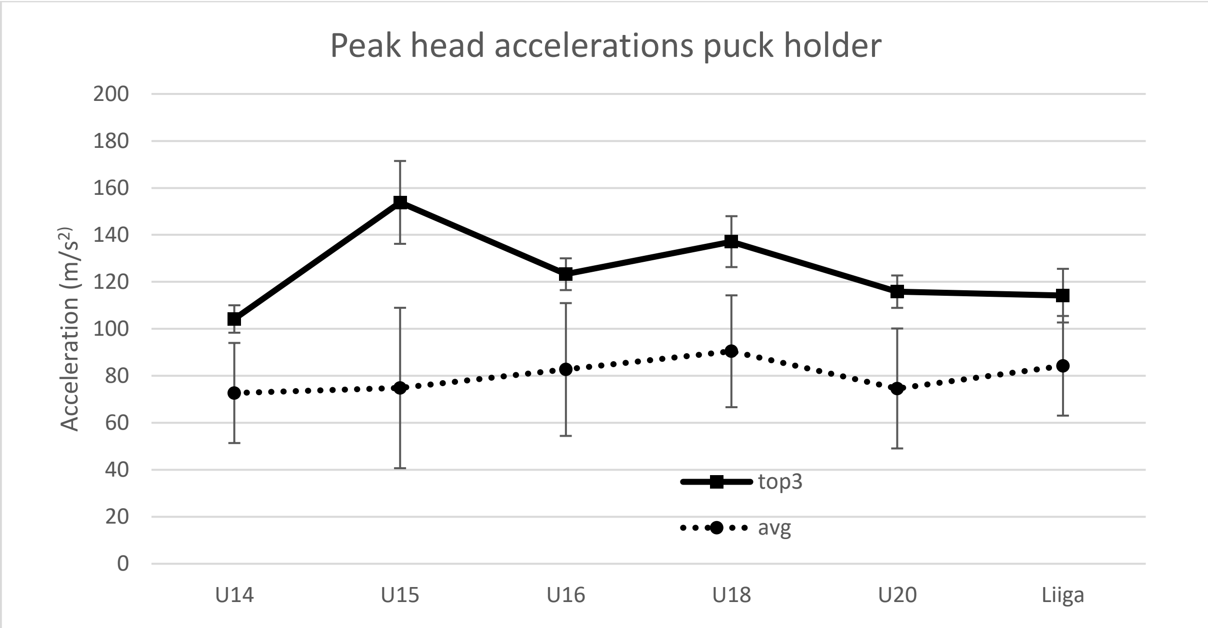

FIGURE 17. Puck holder's peak head acceleration averages compared to top 3 biggest hits peak head accelerations.

When observing the defender, Figure 18 shows that the top 3 biggest hits were not that different from average situation. Therefore, causing big accelerations to puck holder didn't seem to cause high accelerations to player who executed the body check. When looking for body checks which caused the biggest accelerations to defender, those values were clearly higher than average values. The highest value from the body checking drill was 170 m/s^2 (U15 group) and 150 m/s^2 from matches.

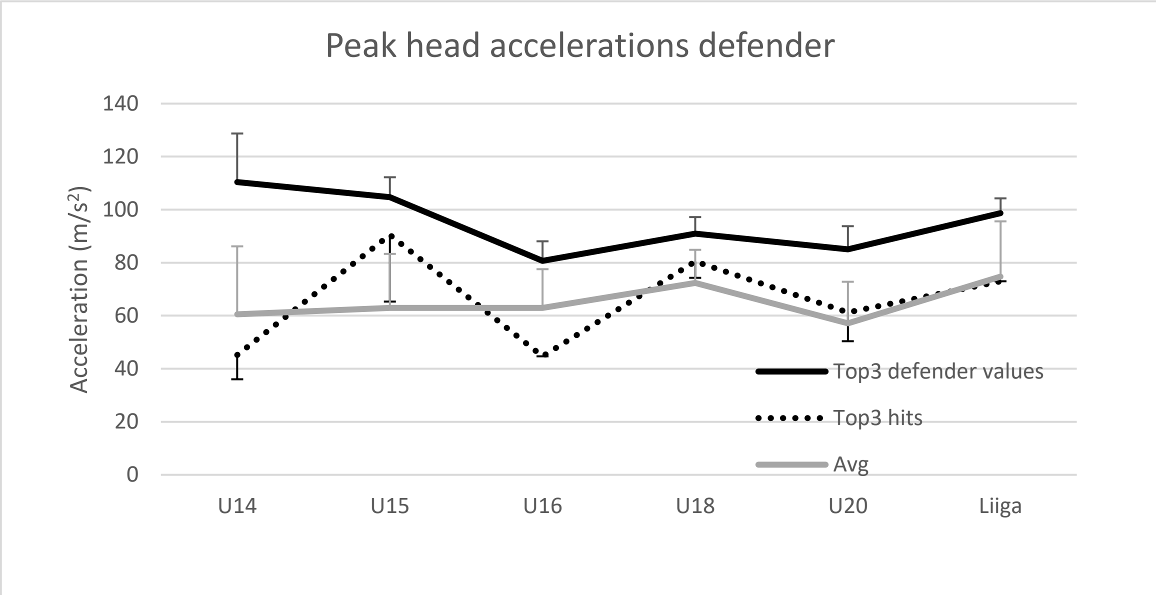

FIGURE 18. Defender’s peak head acceleration values including group average, top 3 biggest hits average and average of defender’s top 3 highest values.

7.3 Board behaviour

Stopping distance increased when the age of players increased. There are statistically significant differences from other groups compared to Liiga groups. Only exception is between Liiga and U18 in the element part. There was not statistically significant difference even though among Liiga group the stopping distance was still greater. Figure 19 shows stopping distances graphically.

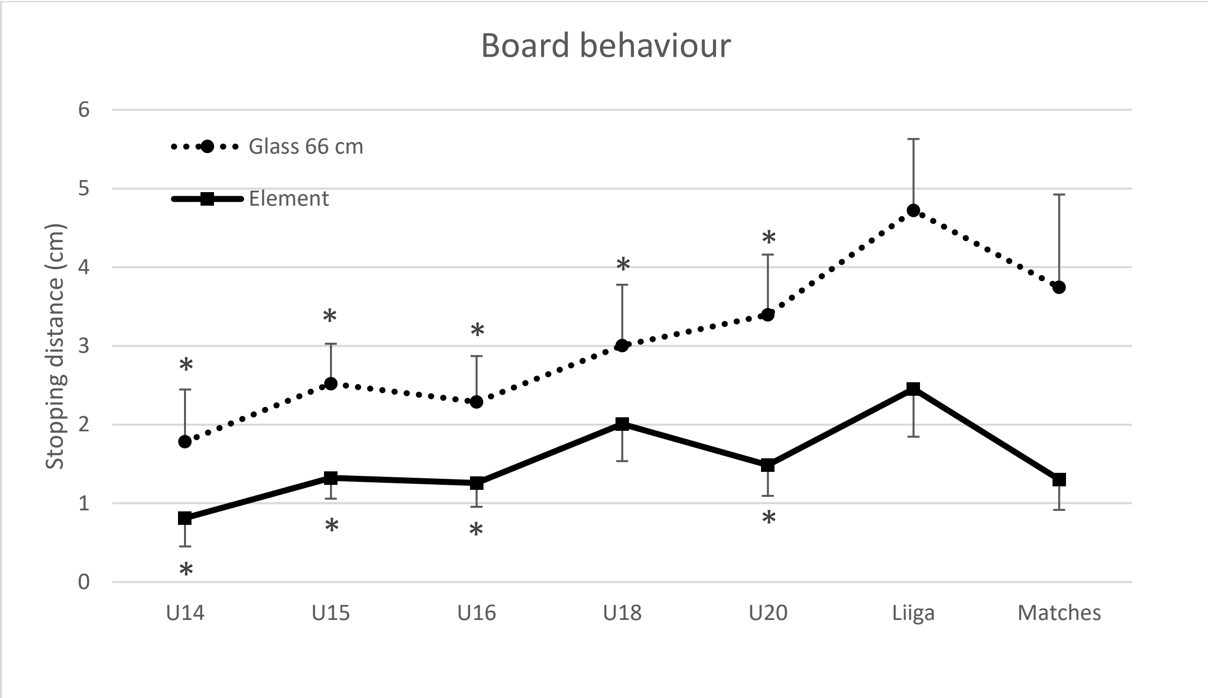

FIGURE 19. Stopping distances of element and glass part of the board. * shows statistically significant differences compared to Liiga group (p<0.05).

Figure 20 shows differences in the element part between group averages and top 3 biggest hits. Stopping distance was little bit greater in bigger hits.

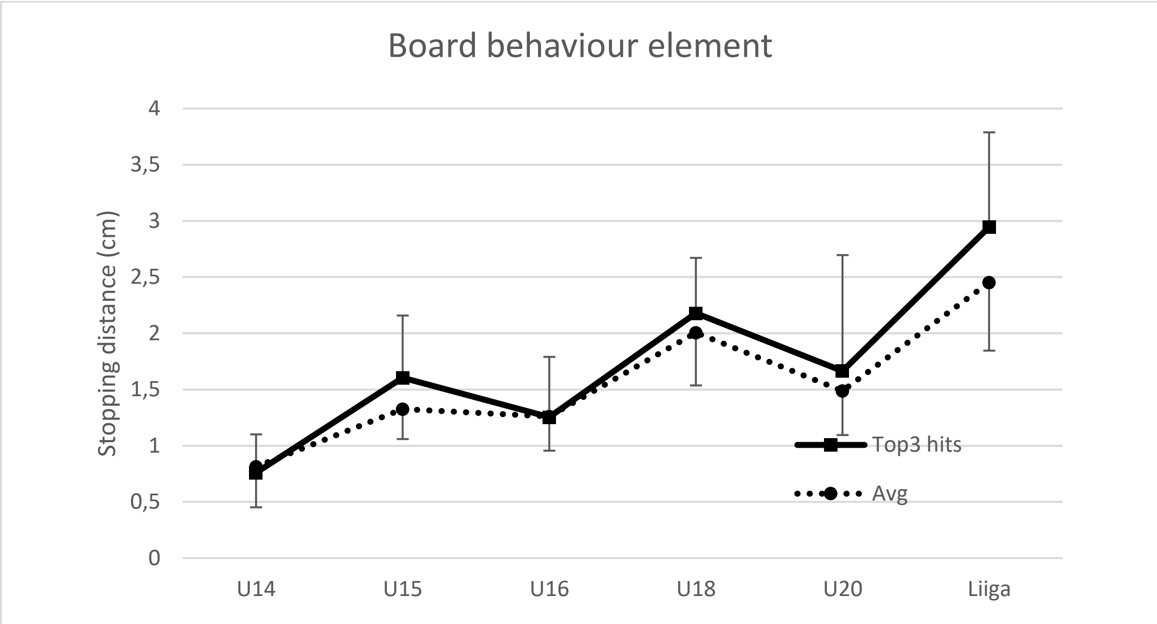

FIGURE 20. Stopping distance of the element part between group averages and averages from top 3 biggest hits.

8 DISCUSSION

Ice hockey body checks and contacts with boards have got some attentions in scientific literature of ice hockey (Tuominen et al 2017a/b, Lynall et al. 2018). Board flexibility has also been studied (Marino & Potvin 2002, Poutiainen et al. 2014) but combination of board behaviour, real checking situation together with players under 15 years, is something which hasn't been seen. Results of this study show that some variables behave as expected and something was little bit a surprise. It was obvious that board stopping distances were much greater for heavier and older players as it was hypothesised, but it was unexpected that head peak accelerations were quite similar between all groups on average. Hypothesis was that juniors would have higher head accelerations.

8.1 Player velocities

Player velocities of 14,4 to 21,6 km/h correspond well what are typical skating speeds in matches. Most of active time on ice is done usually with velocities from 12 to 24 km/h (Keränen et al. 2020). In this study younger groups had significantly lower speeds especially among defenders compared to older groups. It was hypothesized that younger players might have smaller velocities in matches and in checking drill also. Figure 16 shows that defender's perpendicular velocity was higher in hits which caused higher peak head acceleration to puck holder. Same trend was visible in all groups. It is obvious that check hardness is related to body checking velocity and more precisely to velocity differences between two players.

Velocities of puck holder are not so important in the body checking drill because the idea of the puck holder is just to skate along the boards and be ready for the body check. Defender's velocities are more significant for the outcome, in this case especially perpendicular velocity of the defender matters the most. Perpendicular velocity towards boards is the risk factor for injuries which happen with contact to boards. Perpendicular velocity combined with mass is responsible for the displacement of the board.

Match measurements show that defender's velocities were in line with the body checking drill. That shows that the body checking drill represents game situation well. Body checks in matches were done with little bit more perpendicular velocity and less total speed. That fits well to comments how players felt the body checking drill compared to match situations. Puck holder velocities varied a lot in match cases. That is reasonable because sometimes puck holder is almost stationary and sometimes skating fast like in the body checking drill. Average puck holder speed in matches was similar in this and in Bjering (2019) study. For the defender speed difference was notable showing 6.45 to 6.55 m/s^2 in Bjering (2019) study and 4,82 m/s^2 in this study. In these two different studies the body checking situations and methods have been different, therefore these studies are not so comparable.

8.2 Head accelerations

In this study head accelerations were calculated with motion capture methods, where positional data was filtered and then differentiated twice to get acceleration data. One aspect to remember when looking at head accelerations is that the marker represents head but in fact it is in the outer side of the helmet some centimetres above it. That may lead to some differences between the acceleration of the marker and the actual point inside scull. The ideal place for analysis in this case would be centre of mass of brains because concussion is the point of interest in most head injuries in ice hockey. In the used method rotational accelerations couldn't have considered even though they are important aspect as well in concussions (Ji et al. 2014). However, some rotational accelerations affect the marker by increasing its linear acceleration, but sometimes rotational acceleration may dilute the linear acceleration.

Peak head acceleration values varied approximately from 40 to 120 m/s^2 which is 4,1 to 12,2 g. The highest value from checking drill was 170 m/s^2 and 150 m/s^2 from matches. Values are lower than what was found out from matches of U15 league with helmet-based accelerometers. Contacts that caused over 10 g and happened along boards averaged 203 m/s^2 of acceleration. (Mihalik et al. 2010.) In this study accelerations stayed under value of 20 g which has been reported to exceed once every two to three matches among male players (Wilcox et al 2014). Among players at the age of 14 Mihalik et al. (2010) studied head accelerations among under

15-year-old junior ice hockey. In this study there was not a single case with higher that 20 g which tells that our simulated checking drill seems to be safer to players than a normal match. That went as planned because one reason for the drill is to teach players for safe and successful body check situations.

It was unexpected that puck holder head accelerations were quite similar among all groups and among defenders there were more differences between groups. It was expected that the youngest groups would face higher head accelerations due to relatively stiffer board. With the smaller mass of juniors, the board is not so flexible. Maybe the smaller velocities of players dimmish the risk for higher head accelerations. Player's head usually does not touch the glass or the element part of the board. Therefore, it is understandable that the effect of the flexibility of the board is not that linked to head accelerations in relatively safe situations like in our checking drill. However, more flexible board could have seen in even lower head accelerations.

In head accelerations the group of U18 stood out to have the highest peak accelerations on average. It goes in line with their high skating speeds and especially defender's perpendicular velocity. Concussions have reported to be relatively high injury type among U18 players (Tuominen et al. 2017b). One interesting aspect is that when looking for three highest values, "top 3 hits", U15 group shows greater values. Especially for puck holder but also high values for defender. It tells that there is more variation among the youngest players and single body checks with the highest values. Probably it originates from lack of skill and experience in body checks. Older and experienced players can execute harder body check and keep them still relatively safe whereas younger players are not that familiar to receive or give a body check. That results in higher variation among inexperienced players.

Peak head accelerations of defender had little bit less variation inside groups and there were some statistical significances spotted. Groups U18 and Liiga had greater averages than U14, U15 and U20 groups. But again, when looking at top 3 highest values from defender groups, the youngest had the biggest values. Same thing as with puck holders that the least experienced players ended up getting highest head accelerations. Interesting is that body checks which caused the highest head accelerations to puck holder were not the ones that caused the highest head accelerations to defender. Therefore, the hardness of the body check is not so decisive for the head acceleration. At least for the one executes the body check.

8.3 Board behaviour

Factors that affect to stopping distance are player mass and perpendicular velocity towards boards The board behaviour followed well the expected trend that stopping distances are greater with older and heavier subjects. Previous research with ice hockey boards have focused only on adult professional players. They have measured stopping distances with heavy test models and not humans. Their findings are that the element part stopping distance have varied from 1 cm to 6,5 cm depending on the board model and impact velocity. (Poutiainen 2012, Schmitt et al. 2018.) In this study the board stopping distance at the same height was 2 to 4 cm with adult professionals and the board model was one of the very flexible ones. It means that the biggest impacts were not so big compared to those previous studies.

For element part U20 group had much less element displacement than U18 or Liiga groups. That seems to be due to lesser defender's perpendicular velocity. It is interesting that same results were not visible in the glass part. U20 group differed little bit from other groups with their drill performing. They had lot of speed but not much perpendicular velocity. That made their body checks look very soft and safe. From the glass part of the board, we can still see big stopping distances. That indicates that their body checks have emphasised more shoulder and upper body than in other groups. The top three biggest hits caused greater stopping distance in all groups. It is most likely due to higher velocities towards boards.

Between U15 and U16 differences are minimal in board behaviour and results show that board was more flexible for U15 group than for U16. Between those groups average weight was 65,9 and 66,6 kg and that explains similar board behaviour. But the fact that stopping distances were greater for U15 group is surprising because U16 showed higher velocities at the time of contact. That difference can be explained with the variation of results and the difference isn't statistically significant.

Even though stopping distances from element and glass part were much lower for lighter or younger players, that is not visible in head acceleration values. Therefore, it seems, that the relatively stiffer board does not give clearly higher risk for juniors compared to older counterparts. It accounts maybe only for safe body checking drill situation. It is unknown what happens in unanticipated collision to board for example, and we should not forget that flexibility of the board lowers injury risk in head and shoulder injuries (Tuominen et al. 2017a, Tuominen et al. 2017b). It can be that younger players don't need relatively as flexible boards than adults because of smaller skating velocities. But most likely additional flexibility of the board would not have any negative effects to juniors. It could provide even better safety for players.

8.4 Board accelerometers

Accelerometers have been used previously to approximate the magnitude of a body check (Poutiainen et al. 2014). That was primary reason to take them into this research as well. In this research there were other ways to determine body check toughness better than accelerometers in boards. They are player velocities and displacement of the board. Especially the stopping distance of the board is more useful to describe board behaviour than accelerometers. Accelerometers tell more about the initial contact but not about the flexibility what affects players. High peak values from board attached accelerometers predict contact with hard surface without deformation, such as hockey stick or puck. High energy contacts with player don't give so big peak values because of deformation of body posture, body tissues and equipment. The collision to board is very complex that is very difficult to interpret exact effective mass from the player. Knowing effective mass added to board acceleration could give more possibilities to approximate board stiffness for example.

8.5 Strength and limitations of the study

The big strength of this study is that different age groups took part and comparison was possible to do between them. Similarity between the drill and matches was good. That tells those results what were got from drills can be generalized to real match situations. All subjects were high level from oldest groups. And all juniors were somehow experienced with competitive ice hockey. Even though match body checks were comparable to drill setup, the position where checks were filmed, wasn't the most active in regards of body checks. Places closer to the corner part of the rink got more body checks. That's why despite of many matches, only few body checks were analyzed.

How players performed in the drill, gives room for speculation. Even though drill was well instructed, every group had its own way to perform the drill. Liiga and U20 performed without a coach, whereas younger groups had somebody to observe and guide. There was a lot of difference how coach was guiding. U18 coach gave lot of feedback whereas U14 coach only followed. U20 group looked to take the safest approach and keep body checks quite soft despite of high skating speeds.

Some attention must be given to peak head acceleration measurements. Loose helmet can cause some unreliability and the exact marker position varied because of small differences in helmets. Camera setting could affect so, that short peaks might not be seen due to 250 fps videos. That data collection rate is not such a problem because head accelerations which duration are less than 3 milliseconds are not concussion risk (Versace 1971). The setup for head accelerations was not optimal, but values were clearly matching with direct estimations from videos which body check seemed to cause bigger head acceleration values. And values seem to fit to expectations based on previous studies (Mihalik et al. 2010, Wilcox et al. 2013) so, that results seem to be trusthworthy. Optimal way would be to measure acceleration with accelerometers instead of video analysis. That would make data more accurate. Accelerometers have been used in ice hockey helmets in some studies (Wilcox et al. 2014, Mihalik et al. 2010), or in test dummy. (Potvin et al. 2019, Schmitt et al. 2018). It was initial plan to attach accelerometers to players' helmets, but that plan had to be changed because sensors were not available.

8.6 Conclusion

This study shows that there are small differences between age groups in body checking situations. U18 group performs body checks already at the intensity of adult professional players. Youngest groups perform checks with little bit smaller velocities but among them, there is lot of variation in checks. In head accelerations there is not visible clear differences for puck holder, but for the player who checks, there is bigger head peak accelerations for groups that check with higher perpendicular velocity. When looking at highest peak head acceleration values, youngest groups have the biggest values. That goes in line that they have much variation in their checks. To reduce the risk for juniors, it can be proposed that body checking practice is started with low perpendicular velocities and gradually increasing the velocity when players get more experienced. Controlling the perpendicular velocity can be done by altering the angle of arrival of the body check.

There could be two reasons for the highest head acceleration values among juniors despite that their velocities where lower. Either it is because of player inexperience or that board structure is not so flexible for juniors. Board displacement was clearly smaller for groups with smaller mass, which means younger players on average. Peak head acceleration values don’t seem to be too high when these kinds of body checks happen occasionally. To understand better the role of board to peak head accelerations it would be useful to compare checks between two different board systems among same player groups.

REFERENCES

Agel, J., Dompier, T., Dick, R. & Marshall, S. 2007. Descriptive Epidemiology of Collegiate Men’s Ice Hockey Injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 Through 2003–2004. Journal of Athletic Training 42(2):241–248.

Aguiar, O., Potvin, B., Yang, Y., Hua, K., Bruschetta, M., Virani, S. & Robinovitch, S. 2020. American society of biomechanics journal of biomechanics award 2019: Circumstances of head impacts in men’s university ice hockey. Journal of Biomechanics Vol 108. https://doi.org/10.1016/j.jbiomech.2020.109882

Allison, M., Kang, Y., Bolte, J., Maltese, M. & Arbogast, K. 2013. Validation of a Helmet-Based System to Measure Head Impact Biomechanics in Ice Hockey. Medicine & Science in Sports & Exercise 46(1) 115–123.

Allison, M., Kang, Y., Maltese, M., Bolte, J. & Arbogast, K. 2015. Measurement of Hybrid III Head Impact Kinematics Using an Accelerometer and Gyroscope System in Ice Hockey Helmets. Annals of Biomedical Engineering Vol. 43, No. 8, 1896–1906.

Biasca, N., Wirth, S. & Tegner, Y. 2002. The avoidability of head and neck injuries in ice hockey: an historical review. British Journal of Sports Medicine. 36:410–427.

Bjering, B. 2019. Estimations of 3D velocities from a single camera view in ice hockey. Degree project in Medical Engineering Stockholm Sweden 2019. School of Engineering Sciences in Chemistry, Biotechnology and Health. Availabe: http://www.diva-portal.org/smash/record.jsf?pid=diva2:1330646

Brocherie, F., Girard, O. & Millet, G. 2018. Updated analysis of changes in locomotor activities across periods in an international ice hockey game. Biology of Sport, Vol 35 No3.

Chiarlitti, N., Delisle-Houde, P., Reid, R., Kennedy, C. & Andersen, R. 2017. Importance of Body Composition in the National Hockely League Combine Physiological Assessments. Journal of Strength and Conditioning Research 32(11)/3135–3142.

Cusimano, M., Cho, N., Khizer, A., Shirazi, M., McFaull, S., Do, M., Wong, M. & Russel, K. 2013. Mechanisms of Team-Sport-Related Brain Injuries in Children 5 to 19 Years Old: Opportunities for Prevention. PLOS ONE Vol. 8 Is. 3.

Daneshvar, D., Baugh, C., Nowinski, C., McKee, A., Stern, R. & Cantu, R., 2011. Helmets and Mouth Guards: The Role of Personal Equipment in Preventing Sport-Related Concussions. Clinical Sports Medicine. 30(1): 145–163. doi:10.1016/j.csm.2010.09.006

Fischler, S. W., Fischler, S. I., Stanley I. and Eskenazi, G. 2020. Ice hockey. Encyclopedia Britannica. Available: https://www.britannica.com/sports/ice-hockey Cited 22.4.2021

Flik, K., Lyman, S. & Marx, R. 2005. American Collegiate Men's Ice Hockey An analysis of Injuries. The American Journal of Sports Medicine. Vol 33 No. 2.

Hockey Canada 2021. Teaching checking, Body checking. Available: https://www.hockeycanada.ca/en-ca/hockey-programs/players/essentials/positions-skills/checking Cited 4.5.2021.

Hutchison, M., Comper, P., Meeuwisse, W. & Echemendia, R. 2013. A systematic video analysis of National Hockey League (NHL) concussions, part II: how concussions occur in the NHL. The BMJ 49:547–551.

IIHF 2019. IIHF Official Rule Book 2018 – 2022. International Ice Hockey Federation. Available: https://www.iihf.com/en/statichub/4719/rules-and-regulations cited 27.4.2021.

Iltalehti 2018. Älä usko SM-liigatähtien verotietoja - oikeasti palkat ovat paljon isompia: Peräti 117 pelaajaa tienasi yli 100 000 euroa! Available: https://www.iltalehti.fi/smliiga/a/f997da8f-e0f5-4e73-a7eb-11c3dd193c3c cited: 27.4.2021.

Ji, S., Zhao, W., Li, Z. & McAllister, T. 2014. Head impact accelerations for brain strain-related responses in contact sports: a model-based investigation. Biomechanics and Modeling Mechanobiology. 13(5): 1121–1136.

Karton, C. & Hoshizaki B. 2018. Concussive and subconcussive brain trauma: the complexity of impact biomechanics and injury risk in contact sport. Handbook of Clinical Neurology. Vol. 158, 39–49.

Keränen, T., Häyrinen, M., Karjalainen, A., Mikkola, J. & Vesterinen, V. 2020. Jääkiekon lajivaatimukset ja testaaminen. Jääkiekkoliiton fysiikkavalmennuksen webinaari. Available: https://kihuenergia.kihu.fi/tuotostiedostot/julkinen/2020_ker_jkiekonlaj_sel66_87360.pdf cited 28.4.2021

Laaksonen, A. 2011. Jääkiekon lajianalyysi ja valmennuksen ohjelmointi. Valmentajaseminaari, University of Jyväskylä.

LaPrade, F., Surowiec, R., Sochanska, A., Hentkowski, B., Martin, B., Engebretsen, L. &Wijdicks, C. 2014. Epidemiology, identification, treatment and return to play of musculoskeletal-based ice hockey injuries. British Journal of Sports Medicine 48:4–10.

Liiga 2021. Liiga.fi/tilastot. Available: www.liiga.fi cited 27.4.2021.

Lorentzon, R., Wedrén, H. & Pietilä, T. 1988. Incidence, nature and causes of ice hockey injury. The American Journal of Sports Medicine Vol. 16, No. 4.

Lynall, R., Mihalik, J., Pierpoint, L., Currie, D., Knowles, S., Wasserman, E., Dompier, T., Comstock D., Marshall, S. & Kerr, Z. 2018. The First Decade of Web-Based Sports Injury Surveillance: Descriptive Epidemiology of Injuries in US High School Boys' Ice Hockey (2008–2009 Through 2013–2014) and National Collegiate Athletic Association Men's and Women's Ice Hockey (2004–2005 Through 2013–2014). Journal of Athletic Training 53(12) 1129–1142.

Länsi-Suomi 2016. Kiekkoareena selvitti: Minkä kokoisia Suomen kaukalot ovat? Available: https://ls24.fi/urheilu/kiekkoareena-selvitti-minka-kokoisia-suomen-kaukalot-ovat cited 28.4.2021

Marino, W. & Potvin, J. 2002. Impact Characteristics of Two Types of Hockey Arena Boards. Paper Presented at the 20th Symposium of International Society of Biomechanics in Sport, Cáceres, Extremadura, Spain.

Mihalik, J., Blackburn, T., Greenwald, R., Cantu, R., Marshall, S. & Guskiewicz, K. 2010. Collision Type and Player Anticipation Affect Head Impact Severity Among Youth Ice Hockey Players. Pediatrics 125(6). doi: 10.1542/peds.2009-2849

Mosenthal, W., Kim, M., Holzshu, R., Hanypsiak, B. & Athiviraham, A. 2017. Common Ice Hockey Injuries and Treatment: A Current Concepts Review. American College of Sports Medicine Vol. 16 No. 5.

Mölsä, J., Airaksinen, O., Näsman, O. & Torstila, I. 1997. Ice Hockey Injuries in Finland A Prospective Epidemiologic Study. The American Journal of Sports Medicine, Vol 25 No 4.

NHL 2020. National Hockey League Official Rules 2020 – 2021. Available www.nhl.com cited: 27.4.2021.

Pfister, T., Pfister, K., Hagel, B., Ghali, W. & Ronksley, P. 2016. The incidence of concussion in youth sports: a systematic review and meta-analysis. The BMJ. 50:292–297.

Pohjanvirta, V. 2021. Nuoren jääkiekkoilijan oheisharjoittelun analyysi ja ohjelmointi. Lajianalyysi, University of Jyväskylä.

Potvin, B., Aguiar, O., Komisar, V., Sidhu, A., Elabd, K. & Robinovitch, S. 2019. A comparison of the magnitude and duration of linear and rotational head accelerations generated during hand-, elbow- and shoulder-to-head checks delivered by hockey players. Journal of Biomechanics 91 43–50.

Poutiainen, P. 2012 Comparison of Impact Characteristics of Different Ice Hockey Dasher Boards. Master Thesis in Biomechanics. University of Jyväskylä.

Poutiainen, P., Peltonen, J., Isolehto, J. & Avela, J. 2014. Comparison of impact characteristics of different ice hockey dasher boards. European Journal of Sport Science, 14:1, 11-18, DOI: 10.1080/17461391.2012.725106

Rantala, O. 2022 Oral interview of an ice hockey referee. 5.7.2022 Jyväskylä

Renton, T., Howitt, S. & Marshall, C. 2019. Lifetime prevalence of concussion among Canadian ice hockey players aged 10 to 25 years old, 2014 to 2017. Journal of Canadian Chiropractic Association 63(2).

Rouvali, T. 2014. Jääkiekon lajianalyysi ja valmennuksen ohjelmointi. Lajianalyysi, University of Jyväskylä.

Rousseau, P. & Hoshizaki, T. 2015 Defining the effective impact mass of elbow and shoulder strikes in ice hockey. Sports Biomechanics. 14:1. 57-67.

Schmitt, K., Muser, M., Thueler, H. & Bruegger, O. 2018. Crash-test dummy and pendulum impact tests of ice hockey boards: greater displacement does not reduce impact. The BMJ 52;1–7.

Statista, 2021a, Average annual player salary in National Hockey League 2019/20, by team. Available: https://www.statista.com cited 21.4.2021

Statista, 2021b, National Hockey League franchise value by team in 2020. Available: https://www.statista.com cited 21.4.2021

Suomen Jääkiekkoliitto 2018. Jääkiekon virallinen sääntökirja 2018–2022. Suomen Jääkiekkoliitto ry ja IIHF. Available: https://liiga.fi/media/uploads/SA%CC%88A%CC%88NTO%CC%88KIRJA%202018-2022.pdf cited 27.4.2021.

Suomen Jääkiekkoliitto 2020. Suomen Jääkiekkoliiton Kilpailusäännöt 2020–2021. Available: https://www.finhockey.fi/index.php/component/k2/item/137-kilpailusaannot cited 28.4.2021

Tearse, H. 2011. Minnesota Hockey Body Contact & Checking Progression Drills for Bantams. [Video] Available: https://www.youtube.com/watch?v=c2uzzQEvdUE Cited 4.5.2021.

Tuominen, M., Stuart, M., Aubry, M., Kannus, P. & Parkkari, J. 2015 Injuries in men's international ice hockey: a 7-year study of the International Ice Hockey Federation Adult World Championship Tournaments and Olympic Winter Games. The BMJ 49:30–36.

Tuominen, M., Stuart, M., Aubry, M., Kannus, P. & Parkkari, J. 2017a. Injuries in world junior ice hockey championships between 2006–2015. The BMJ 51:36–43.

Tuominen M., Hänninen, T., Parkkari, J., Stuart, M., Luoto, T., Kannus, P. & Aubry M. 2017b. Concussion in the international ice hockey World Championships and Olympic Winter Games between 2006 and 2015. The BMJ 51:244–252.

Twist, P. & Rhodes, T. 1993. The Bioenergetic and Physiological Demands of Ice Hockey. National Strength and Conditioning Association Journal Vol 15 No 5.

USA HOCKEY 2011. Body Checking (Off-Ice Lesson) – USA Hockey Safety. [Video] Available: https://www.youtube.com/watch?v=XvNwI6AVaqU Cited 4.5.2021.

Versace, J. 1971. A review of the Severity Index. SAE Technical Paper 710881.

Vigh-Larsen, J., Beck, J., Daasbjerg, A., Knudsen, C., Kvorning, T., Overgaard, K., Andersen, T. & Mohr, M. 2019. Fitness Characteristics of Elite and Subelite Male Ice Hockey Players: A Cross-Sectional Study. Journal of Strength and Conditioning Research 33(9)/2352–2360.

Wilcox, B., Machan, J., Beckwith, J., Greenwald, R., Burmeister, E. & Crisco, J. 2014. Head-Impact Mechanisms in Men's and Women's Collegiate Ice Hockey. Journal of Athletic Training 49(4):514–520, doi: 10.4085/1062-6050-49.3.19

Yde, J. & Nielsen, A. 1990 Sports injuries in adolescent's ball games: soccer, handball and basketball. British Journal of Sports Medicine Vol 24 No 1, 51–54.

Zatsiorsky, V. M. 2000. Biomechanics in Sport: Performance Enhancement and Injury Prevention. Cambridge, USA: Blackwell Science, University Press. E-Book.

Zhang, L., Yang, K. & King, A. 2004. A Proposed Injury Treshold for Mild Traumatic Brain Injury. Journal of Biomechanical Engineering Vol 126, 226–236.

APPENDICES

APPENDIX 1. Table of average values and standard deviations.

Variable	U14	U15	U16	U18	U20	Liiga	Matches
Defender speed (m/s)	4,28 ± 0,52	4,41 ± 0,61	4,97 ± 0,57	5,29 ± 0,72	5,25 ± 0,61	5,47 ± 0,58	4,82 ± 0,77
Defender perpendicular velocity (m/s)	2,79 ± 0,57	2,66 ± 0,49	2,88 ± 0,46	3,50 ± 0,65	2,66 ± 0,52	3,22 ± 0,26	3,73 ± 0,69
Defender maximum acceleration (m/s^2)	60,49 ± 25,69	62,96 ± 20,37	62,97 ± 14,59	72,39 ± 12,47	57,14 ± 15,67	74,75 ± 20,85	65,79 ± 12,60
Defender mass (kg)	54,35 ± 4,15	66,62 ± 9,75	66,65 ± 4,42	73,05 ± 6,04	84,23 ± 4,34	87,00 ± 8,08	
Puck holder speed (m/s)	4,35 ± 0,53	5,10 ± 0,57	5,36 ± 0,55	6,15 ± 0,34	5,30 ± 0,49	5,27 ± 0,58	4,42 ± 2,22
Puck holder perpendicual velocity (m/s)	0,60 ± 0,40	0,87 ± 0,48	0,87 ± 0,39	0,95 ± 0,44	0,63 ± 0,32	0,68 ± 0,41	1,08 ± 0,51
Puck holder maximum acceleration (m/s^2)	72,70 ± 21,31	74,83 ± 34,14	82,70 ± 28,27	90,46 ± 23,81	74,63 ± 25,53	84,27 ± 21,21	88,19 ± 35,57
Puck holder mass (kg)	55,25 ± 4,45	66,23 ± 10,06	66,76 ± 4,45	73,95 ± 5,28	84,23 ± 4,34	87,00 ± 8,08	
Combined perpendicual momentum (kgm/s)	185,50 ± 42,87	234,03 ± 46,88	240,37 ± 51,53	323,32 ± 56,02	277,06 ± 48,80	337,05 ± 32,23	
Defender's angle of arrival (°)	42,39 ± 12,26	38,07 ± 9,03	33,91 ± 9,06	41,38 ± 4,54	30,86 ± 5,90	36,53 ± 4,14	54,03 ± 14,18
Stopping distance of glass 66 (cm)	1,78 ± 0,66	2,52 ± 0,51	2,29 ± 0,58	3,00 ± 0,77	3,39 ± 0,77	4,72 ± 0,91	3,74 ± 1,18
Stopping distance of glass 30 (cm)	1,51 ± 0,71	2,44 ± 0,63	2,09 ± 0,61	3,00 ± 0,79			
Stopping distance of element (cm)	0,81 ± 0,36	1,33 ± 0,27	1,26 ± 0,30	2,01 ± 0,47	1,49 ± 0,39	2,45 ± 0,61	1,30 ± 0,39

APPENDIX 2. Table of top 3 hardest hits averages and standard deviations.

Top3	U14	U15	U16	U18	U20	Liiga
Defender speed (m/s)	4,62 ± 0,47	3,79 ± 0,43	5,27 ± 0,82	5,47 ± 0,51	5,57 ± 0,59	5,85 ± 0,38
Defender perpendicular velocity (m/s)	2,98 ± 0,39	3,18 ± 0,43	3,03 ± 0,48	4,12 ± 0,56	3,04 ± 0,22	3,32 ± 0,13
Defender maximum acceleration (m/s^2)	45,2 ± 9,17	90,5 ± 25,16	44,7 ± 0	80,50 ± 6,20	61,30 ± 10,91	73 ± 0
Defender mass (kg)	57 ± 5,35	60,33 ± 0,47	67,33 ± 0,47	70,50 ± 5,50	83,67 ± 3,09	93 ± 7,07
Puck holder speed (m/s)	4,87 ± 0,31	4,38 ± 0,37	4,84 ± 0,49	5,99 ± 0,35	5,24 ± 0,25	5,01 ± 0,51
Puck holder perpendicual velocity (m/s)	0,47 ± 0,18	1,15 ± 0,26	1,11 ± 0,49	1,12 ± 0,14	0,43 ± 0,29	0,39 ± 0,14
Puck holder maximum acceleration (m/s^2)	104,2 ± 5,83	153,83 ± 17,64	123,27 ± 6,76	137,13 ± 10,84	115,83 ± 6,89	114,13 ± 11,42
Puck holder mass (kg)	53,67 ± 3,30	58,67 ± 1,89	70,67 ± 2,36	72,33 ± 5,19	82,13 ± 4,40	93,33 ± 6,60
Combined perpendicual momentum (kgm/s)	197,20 ± 31,45	259,83 ± 18,58	225,31 ± 83,11	371,34 ± 33,18	287,88 ± 28,34	343,94 ± 20,82
Defender's angle of arrival (°)	40,46 ± 3,49	56,81 ± 2,33	25,56 ± 15,95	48,68 ± 2,82	33,39 ± 3,22	34,87 ± 3,81
Stopping distance of glass 66 (cm)	1,68 ± 0,34	3,08 ± 0,56	2,15 ± 0,54	2,95 ± 0,49	3,63 ± 1,03	5,48 ± 0,84
Stopping distance of glass 30 (cm)	1,56 ± 0,67	3,29 ± 0,90	2,07 ± 0,48	3,29 ± 0,89		
Stopping distance of element (cm)	0,76 ± 0,15	1,60 ± 0,33	1,25 ± 0,172	2,18 ± 0,44	1,66 ± 0,26	2,95 ± 0,78