

COMPARISON OF IMPACT CHARACTERISTICS OF DIFFERENT ICE HOCKEY ARENA DASHER BOARDS

Piritta Poutiainen

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Department of Biology of Physical Activity

University of Jyväskylä

Supervisor: Janne Avela

ABSTRACT

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During last years the incidence and severity of ice hockey related concussions have been increased and, hence, something should be done to stop this growth. The main aim of this study was to find out how dasher board materials and structures affect impact characteristics and, thereby, the risk of concussions. The measurements were divided into two parts; in the first part, the physiological characteristics of body checks were determined in real game measurements, and the second part, consisted of simulation of body checks in the laboratory. High speed cameras and accelerometers were used to collect data. More flexible protective shielding material (dasher board B) resulted in lower peak force and stiffness as well as greater stopping distance compared to the other dasher boards. However, the dasher board with flexible protective shielding material including shielding supporting posts resulted to be non-consistent and, thereby, that kind of dasher boards cannot be classified as safe ones. Single-framed dasher board was detected to be more flexible than dual-framed counterpart and heavier protective shielding resulted in significantly higher element stiffness ($p < .05$). With this study it was shown that modification of the materials and structures of the dasher boards give an opportunity to affect impact characteristics and, thereby, the concussion risk. In the light of the results and the epidemiology of concussions it seems that the most safety dasher board would be single-framed with light and flexible protective shielding material and it would not include shielding supporting posts. However, there are still many questions under debate and, therefore, the investigation must be continued.

Keywords: ice hockey, dasher board, concussion, impact characteristics, peak force, stopping distance, stiffness, energy absorption

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1 INTRODUCTION

Ice hockey has great risk for injury because it combines high speeds with aggressive physical play (Flik et al. 2005) and the players have become bigger, faster and stronger (Biasca et al. 2002). During last years the incidence and severity of ice hockey related concussions as well as the costs of treatments have been increasing (Biasca et al.2002) and, hence, something should be done. Equipment development, rule enforcement, and instructions on how to give and receive body checks are important in reducing the amount of concussions (Smith et al 1997). In addition, modifying and developing playing environment can serve to reduce concussion rate by affecting impact characteristics.

Many topics related with players safety and ice hockey arena dasher board materials and structures are under debate. However, the effects of dasher board materials and structures on impact characteristics and, therefore, on the risk of concussions, have not been widely investigated. Marino & Potwin (1998) have conducted a study in which they compared impact characteristics of standard and “new and soft” dasher boards, but the paper has been published only partly. Thereby, the topic is current and the fact that impact characteristics of ice hockey arena dasher boards have not been scientifically studied before emphasizes the need for this study.

The aim of this study was to reveal how dasher board materials and structures affect impact characteristics and, thereby, the risk of concussions. The main research problems were to find out the differences in impact characteristics between three different ice hockey arena dasher boards, reveal how pronounced the differences are and expand understanding of what explains them. In addition, it was of interest to study how much impact characteristics differ between different impact locations of protective shielding. Also a comparison of impact characteristics of single- and dual-framed dasher boards was realized to find out what effects the frame type has on element stiffness. An effect of protective shielding mass on element stiffness was also studied.

2 ICE HOCKEY

Ice hockey is played in many countries throughout the world (Flik et al. 2005), but it is especially popular in northern and eastern parts of Europe and in the North America (Mölsä et al. 1999). In Finland ice hockey is one of the most popular sports and there are about 67 000 registered players in the Finnish Ice Hockey Association in the country with a population of only 5.2 million people (International Ice Hockey Federation 2010a). More than 3 million spectators follow the official games every season (Mölsä et al. 1997) and there are over 240 indoor rinks in Finland (International Ice Hockey Federation 2010a.).

Nowadays ice hockey is played by both men and women (Flik et al. 2005). By men it has been played since the mid-1800s and the first rules were laid down as early as in 1879. Already in the late 1800s also women played ice hockey, but in the mid-1900s for a long period of time, playing ice hockey was dormant for women. (Agel & Harvey 2010.) In Finland from 1928 ice hockey has been played competitively, but Finnish National Hockey League was not founded until 1975. In 1983 an official women's National Hockey League was played for the first time. (Suomen jääkiekkoliitto 2011.) At the American collegiate ice hockey has been played competitively since 1948 by men, but not until 2001 by women. (Agel & Harvey 2010.)

2.1 Characteristics of ice hockey

Ice hockey is a complex sport with many different tasks during a game (Bossone et al. 2003). The game has an intermittent nature with repeated, high intensity bouts of skating, interspersed with on-ice gliding and rest between shifts (Spiering et al. 2003). The game has complex requirements: players have to have a combination of strength, agility, balance, skill, and controlled aggression, thus, at the elite level the players are highly conditioned athletes (Flik et al. 2005). High-performance requires unique strength and endurance, which are facilitated by training (Bossone et al. 2003).

uring the whole ice hockey match the player covers a distance of about 5,553 meters. The playing time of each player varies an average from 20.7 to 28.0 minutes with each shift lasting between 81 and 88 seconds. (Green et al. 1976.) Playing a regular shift, man short, and the power play may affect the playing times (Smith et al. 1997).

The players are working at around 70-80 % of their maximal aerobic power and their heart rate (HR) is remaining really high during the whole game, an average 87-92 % of the HR_{max} . The HR remains high also during the rest intervals due to their short duration. High intensity of the game can be seen also from the blood lactate values: after the first period blood lactate has been noted to be four- to fivefold from the value observed before the game, which suggests a significant anaerobic involvement. (Green et al. 1976.) The game may be characterized as an activity showing principally a submaximal metabolic rate with a great participation of anaerobic metabolism (69%), but concurrently with high requirements for aerobic metabolism (31 %) (Seliger et al. 1972).

The performance demands vary within playing position in many team sports, also in ice hockey, and that is why physical and performance characteristics in elite sport appear to be position specific. The players can be divided into three groups in an ice hockey team, goalies, defensemen and forwards, based on the tasks they mainly have during the game. Because there are more similarities in the demands between forwards and defensemen than goalies, forwards and defensemen are more homologous to each other and more different from goalies in fitness, skating, and physical performance characteristics. Partly, in childhood, the selection for sport and playing position is based on physical characteristics, fitness, and skills that the child has. (Geithner et al. 2006.)

2.2 Differences in the game between continents, genders and ages

Differences in the game of ice hockey can be seen between different continents, genders and ages. Characteristically ice hockey is quite different when comparing the North American and European games. The North American style of playing is considered to be much more aggressive and physical than in Europe. One important aspect, which makes the North American game “harder”, is the surface area of the rink. In the North

America the rinks are considerably smaller, only 1560 m², compared to the European counterparts, which are on average 1800 m². Due to the smaller playing surface, there are significantly more contacts during the game in the North America and, thereby, the players in the North America are placed at higher risk for contact injuries. (Flik et al. 2005.)

In men's ice hockey the contact between players, so called body checking, is allowed, whereas it is forbidden in women's games (Agel & Harvey 2010). Mostly, but not only, due to the regulations of body checking men's game is overall more physical, whereas in women's ice hockey more attention is paid to skills and fitness (Geithner et al. 2006). Apart from body checking the rules and regulations are same for men and women.

Among the juniors the age at which body checking becomes allowed varies between countries and in the North America also between states. For example in Ontario, Canada, the juniors only at ages 10 to 11 are allowed to body check whereas in Quebec, Canada, body checking has not been allowed before the ages of 14 to 15. (MacPherson et al. 2006.) In Finland body checking is forbidden for juniors less than 14 years (Suomen jääkiekkoliitto 2009). For female juniors' body checking is prohibited at all ages. As a result of allowing body checking the amount of injuries, especially the severe ones such as concussions and fractures, has been increased (MacPherson et al. 2006).

Few other variations exist in regulations between age groups and levels. Variations can be found, just to mention a few, in duration of the period and penalties, in dimensions of the playing surface as well as in regulations related with overtime and game winning shot competition. In regulations related to mandatory equipment, differences can also be found. For example in Finland junior players have to use full-face mask, whereas older players do not need to wear them. They are allowed to play with visors. (Suomen jääkiekkoliitto 2009.)

2.3 Playing environment – a rink

The game of ice hockey is played on a white ice surface known as a rink. There are rinks of different sizes in which ice hockey is played. According to the rules of the International Ice Hockey Federation (IIHF) the rink has to be between 56 and 61 meters long and 26 – 30 meters wide. The corners must be rounded in the arc of a circle with a radius of 7 to 8.5 meters. The rink is surrounded by an element, which consists of a framework and a puck board. The element must extend 1.17 – 1.22 meters above the level of the ice surface. There is a protective shielding located above the element. The protective shielding has to be 1.6 to 2 meters in height on the end zone of the rink and extend to 4 meters from the goal line towards the neutral zone. Along the sides it must be 0.8 – 1.2 meters in height, except in front of the player benches (figure 1). On the end zone protective net must be hanged up above the protective shielding due to spectators safety. (International ice hockey federation, 2010b.)

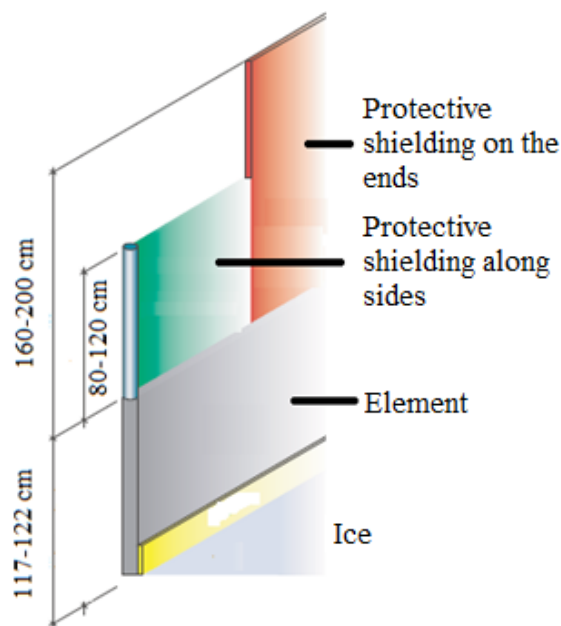


Figure 1. Dimensions of hockey arena dasher board according to the official International Ice Hockey Federation rules (modified from International Ice Hockey Federation 2010a).

There are many challenges when constructing ice hockey arena dasher boards. Apart from players' and spectators' safety, the boards must be also long lasting and give spectators a good viewing experience. When selecting the proper board design, the type of

hockey to be played, other ice sports, spectators seating, and required portability, just to mention a few, must be also taken into account. (Coleman & Sutherland 2007.)

There is diversified selection of elements and protective shielding types installed in ice rinks nowadays (Agel et al. 2007) and all manufacturers have their own products with small differences in materials and structural characteristics. Wide range of materials including snow banks, tree trunks bound together, plywood clad frames and acrylic boards have been used to construct the dasher boards over the years (Coleman & Shutherland 2007). Especially the last decades have brought new technology and designs into dasher board manufacturing in order to improve their quality. There are plenty of different dasher board types with small differences in materials and structures (figure 2) and through design and testing the best combination can be found for each ice hockey rink. (Milton et al. 2002.) In the following paragraphs the materials and mechanical properties of dasher board frames, puck board and protective shielding will be discussed more in detail.

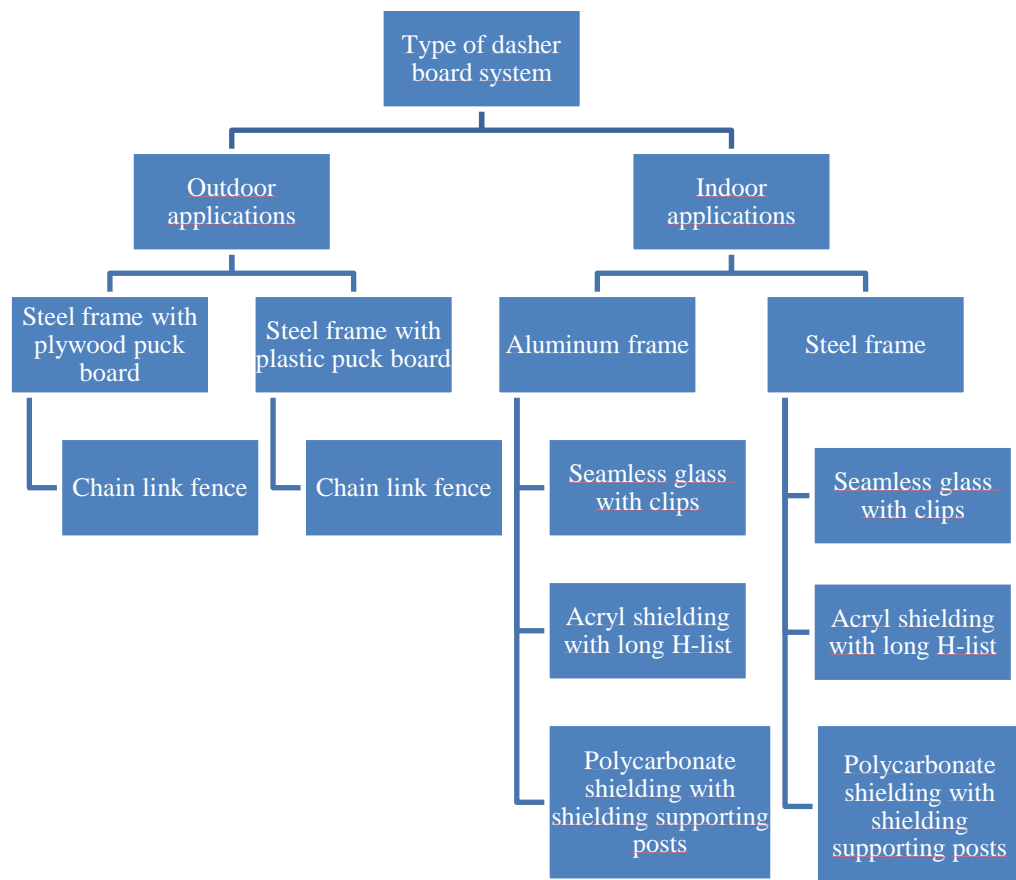


Figure 2. Most common types of dasher board systems.

2.3.1 Dasher board frames

The design, which is nowadays used in dasher board frames, originates from the science behind commercial glass and glazing (Audas 2009). Dasher board frame can be built from wood, fiberglass, steel, aluminum or a combination of these materials (Milton et al. 2002). However, at present metal framed systems are quickly replacing the older construction materials (Coleman & Shutherland 2007). The frames are normally 120 mm or 144 mm thick. In Europe some dasher boards have also been constructed with 72 mm or 96 mm thick frames, but those dasher boards are not resistant for hard impacts. (Coleman & Shutherland 2007.) The dasher board frame can be either single- or dual-framed depending on its structure.

Dasher board frames made of wood are only used for projects with a very small budget and they are more often served for outdoor rinks. Fiberglass frames have existed for more than 30 years, but they have not been proven to hold up over a long cycle in indoor ice hockey environment. Instead, they are optimal for outdoor applications because they do not react to temperature changes as plastic and metals do. (Milton et al. 2002.)

Dasher boards used in indoor applications are most often either aluminum- or steel-framed. Steel-framed dasher boards are stronger than aluminum-framed counterparts. (Audas 2009.) They are also much heavier and commonly used in ice hockey arenas, where limited or no portability is required. However, there are also newer portable steel-framed dasher boards, which can be used in multipurpose arenas. Aluminum-framed dasher boards are lighter and much easier to handle, thus, they are easily removed and reinstalled between different events. (Coleman & Sutherland 2007.) Another advantage for aluminum-framed dasher boards is that mechanically fastened aluminum is not brittle and, thereby, it is not disposed to breakage. Mechanically fastening of the vertical and horizontal pieces permits the dasher board frame to flex elastically upon significant impact, which is suitable for high-impact sport applications such as ice hockey. (Audas 2009.)

Steel frames used in dasher boards are galvanized, which means that there is a layer of zinc over the surface of the steel frame. This is to protect the steel frame from rust: the

zinc is oxidized instead of the steel. However, galvanizing is not self-healing and, thereby, if the galvanizing is disturbed in any place, there is no protection and the rusting process starts immediately. Aluminum frames, instead, are anodized, which refers to a controlled oxidation of the aluminum surface to produce Al_2O_3 , which is a powerful protective layer. Aluminum anodizing is self-healing; thus, such as scratches from skate blades or hole in the aluminum will generate its own layer of protective aluminum oxide. (Audas 2009.) These processes done for the metal frames ensures the high level of quality and longer durability (Coleman & Sutherland 2007).

Many different mechanisms to attach the dasher board frame into the base exist. Nowadays one of the most used systems is so called “ice dam” (figure 3). It allows rotational movement of the board to start just above the ice level, which makes the dasher board system more flexible. (Athletica 2011b.) Furthermore, it diminishes the amount of labor required in changeovers, because there is no need to melt the ice (RAI-TA SPORT 2011b). More traditional system is to anchor the dasher board frame directly to the base slab.

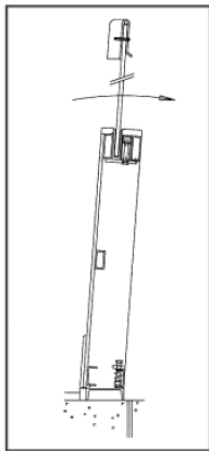


FIGURE 3. Functional model of ice dam (adapted from Athletica 2011b).

2.3.2 Puck board

The puck board is usually made of plastic or wood (International ice hockey federation, 2010b) and together with the dasher board frame it constitutes an element. In metal framed dasher boards the puck board is fastened directly to the metal frame. The thick-

ness varies between 9 mm and 12 mm depending on the applications the rink is used. 12 mm thick puck board is mostly used for moderate to heavy using applications. The color of puck board is often white. (Coleman & Sutherland 2007.)

High Density polyethylene (HDPE) is most commonly used to clad the puck board (Coleman & Sutherland 2007). Polyethylene can resist extreme changes of temperature (from - 50 ° to + 80 °), high impacts and scratchiness and it is, therefore, the best choice for the surface of the puck board (RAI-TA SPORT 2010). HDPE provides long lasting surface and better appearance for puck board compared to more economic cladding materials (Coleman & Sutherland 2007). Also combination of plywood and polyethylene as well as fiberglass and urethane can be used for cladding. Fiberglass provides better puck play, but as a material, it is generally more expensive. (Milton et al. 2002.)

2.3.3 Protective shielding

Protective shielding must be used above the element (International Ice Hockey Federation, 2010). It is not only for keeping the puck in play but also for spectators' safety. The three main types used as protective shielding are: chain link fence, acrylic and tempered glass. In addition to those also laminated safety glass and polycarbonate has been used, but both of them have some limitations and, thus, they are not widely used. (Milton et al. 2002.) Furthermore, manufacturers might have their own special protective shielding materials too.

Chain link fence is commonly used in outdoor applications due to its durability and ability to withstand high abuse. Acrylic shields, instead, are produced especially for multiuse hockey arenas, because they are light and easily handled for facility with quick changeover schedules. Normally acrylic shielding is 12 mm thick, but nowadays in major league arenas they have started to use a protective shielding of 15 mm thick at the end zones of the rink due to harder impacts. Acryl shielding weighs between 15 and 20 kg / m² depending on its thickness. Advantage of an acryl shielding is its ability to flex. However, acrylic shielding has one big disadvantage; it does not provide clear view for the spectators, at least if watching from an angle. (Milton et al. 2002.)

Tempered glass is the easiest protective shielding material to maintain and it does not scratch (Milton et al. 2002), therefore, having long overall life expectancy. In addition, it offers unlimited and undisturbed view for spectators and media. (Coleman & Sutherland 2007.) Thickness of tempered glass protective shielding varies between 12 mm and 15 mm. It is rather heavy weighing 34 to 42 kg / m² and, thereby, it is not optimal for multiuse hockey arenas. (Milton et al. 2002.) During the last years laminated tempered glass has found its way to some professional arenas. Lamination improves spectators' safety; if a glass gets broken, the lamination keeps all the fragments together. However, wider use of the laminated tempered glass has been restricted owing to its costly price. (Coleman & Sutherland 2007.)

Polycarbonate is an ideal material for protective shielding in small competition and training level arenas. It is known among the customers because of its simplicity and easy way of installation as well as lightness and the ease to handle. Polycarbonate protective shielding is made of 8 mm polycarbonate sheets, which are supported by posts made of aluminum. (RAI-TA SPORT 2011a.)

Inter-shielding supports differ depending on the material of protective shielding and dasher board frame design. Nowadays specially designed clips are widely used as shielding supports for tempered glass shielding. Clips allow each protective sheet to move independently upon impact maximizing overall flexibility (figure 4), which is believed to increase the energy absorption. (Athletica 2011b.) With polycarbonate shielding the shielding supporting posts, which are attached directly to the frame, are used (figure 5). Between protective acryl sheets the long H-lists are used. (RAI-TA SPORT 2011a.)



FIGURE 4. Clips allow each piece of protective glass to move independently upon impact (modified from Athletica 2011a).



FIGURE 5. Shielding supporting posts (modified from RAI-TA SPORT 2011a).

2.4 Ice hockey injuries

Ice hockey is a high-speed collision sport (Agel & Harvey 2010), which can be classified as dangerous event (Darling et al. 2011). It combines high speeds with aggressive physical play and therefore has great risk for injury (Flik et al. 2005). Nowadays ice hockey has a tendency towards more aggressive playing. The players have become bigger, faster and stronger, which raise the energy involved in collisions increasing the rate of injuries. (Biasca et al. 2002.) Canadian data suggest that ice hockey injuries already count almost for 10 % of all youth's sport injuries in Canada. Only basketball and soccer cause more injuries. (Emery & Tyreman 2009.)

2.4.1 Injury rates

The amount of ice hockey injuries per year has been increasing during the last decades. Mölsä et al. (2000) were observing the incidence, types, and mechanisms of injuries in Finnish ice hockey players from 1970s through the 1990s. The data was collected at the highest competitive level of ice hockey in Finland, the Finnish National League (FNL). They detected that in the 1970s the injury rate in games was 54 injuries per 1000 player-hours, but in the 1990s the injury rate had increased already to 83 injuries per 1000 player-hours. This indicates that the injury rate increased over 50 % from the 1970s till the 1990s. (Mölsä et al. 2000.) Also in Canada, over the period of 16 years from 1988 –

1989 through 2003 – 2004 a significant average annual increase in game injury rate was observed (1.3 %, $p=.05$) (Agel et al. 2007).

The overall injury rate is around 5 injuries per 1000 athletic exposures (AEs) (Flik et al. 2005). The injury rate is slightly higher in men's compared to women's ice hockey. The difference is explained mainly by differences in the body checking rules: in men's ice hockey body checking is permitted while in women's ice hockey it is forbidden (Agel & Harvey 2010). When observing junior hockey players, the injury rates have been slightly lower compared to those observed in adults. It may be explained, at least partly, by younger players' non-checking leagues. (Emery & Meeuwisse 2006.)

It has been shown in many studies that there are statistically significant differences in injury rates between games and practices (Agel & Harvey 2010; Agel et al. 2007; Emery & Meeuwisse 2006; Flik et al. 2005; Mölsä et al. 2000; Tegner & Loentzon 1991.) Agel & Harvey (2010) reported that in Canada the average injury rate for men during practice was 2.23 injuries per 1000 AEs and in games the comparable rate was as high as 18.68 per 1000 AEs. (Agel & Harvey 2010.) Mölsä et al. (2000), who studied FNL players, did not find as great difference between injury rates as the Canadian researchers, but the difference was anyhow pronounced. According to Mölsä et al. (2000) 75 % of the injuries occurred during the games and 25 % during the practices. (Mölsä et al. 2000.) Based on the findings, it can be seen that in the North America the difference between the game and the practice injury rates is more significant when compared to Europe, which might be due to smaller ice rinks and more aggressive and physical style to play in the North America. Also the methodology used can partly explain the differences; the definition of injury varies among studies (Darling et al. 2011).

Many explanations for the differences between the amount of game and practice injuries can be found. First of all, there are more contacts between players and the style to play is more aggressive and competitive in games (Emery & Meeuwisse 2006). Also the intensity of play is higher in games, which accounts for the injury rates (Agel et al. 2007). Secondly, the hockey players have equipment, which give them good protection unless contact at high speed is involved. The high speed contacts are much more common in

game scenario and rarely occur in practice. Also body checking and other potentially injurious acts occur more often during games than in practices. (Flik et al. 2005.)

2.4.2 Injury mechanisms and risk factors

According to many studies, it is obvious that contact with another player, being unintentional collision or body checking, is the most common cause for an ice hockey injury (Darling et al. 2011; Mölsä et al. 2000). It has been proven that as much as 50 % of injuries occurring during games are related to direct contact with another player or his/her equipment (figure 6) (Agel et al. 2007). Most often injuries are reported by the player receiving the body check and only few, approximately 16 % of those body checks, results in a penalty. Apart from player-to-player contact injuries, also environmental contact injuries and no contact injuries do occur (figure 6). (Emery& meeuwisse 2006).

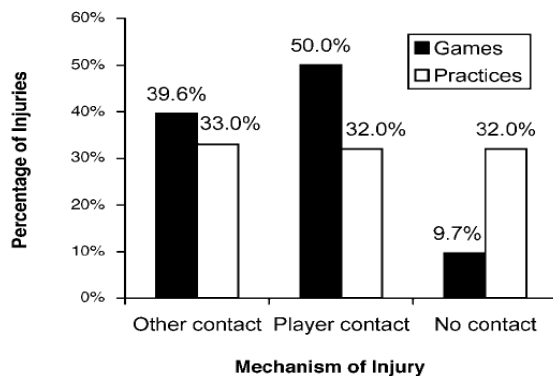


FIGURE 6. Game and practice injury mechanisms. Other contact refers to contact with items such as sticks, pucks, boards, or the ice (adapted from Agel et al. 2007).

As a mechanism of injury the rates of unintentional collision and body checking have continually increased during the last decades. In the 1970s and 1990s unintentional collision was a main mechanism for injury in 8 % and 22 % of all cases, respectively. In 1970s body checking was the main mechanism of injury only for 19 % of all cases, but in the 1990s it already led to 35 % of all injuries. (Mölsä et al. 2000.)

It has been shown that there is an absolute injury risk reduction, when body checking is not allowed. The reduction has demonstrated to be as high as 2.84 injuries per 1000 player-hours. The risk of severe injuries, concussions and severe concussions has noted

to diminish by 0.72, 1.08 and 0.20 injuries per 1000 player-hours, respectively. With respect to practice related injuries, there are not any significant differences between non-checking and checking leagues. No significant differences have been found either between the injury rates associated with other injury mechanisms, like environmental contact or no contact, between checking and non-checking leagues. (Emery et al. 2010.)

Based on these findings it is obvious that body checking should be removed from the younger players' ice hockey to make the game safer (Darling et al. 2011). Already many Academies in North America, such as the American Academy of Pediatrics and the Canadian Academy of Sports Medicine, have given some guidelines suggesting that body checking should be forbidden until the age of 15 or even 16 (Macpherson et al. 2006). However, removing body checking totally from ice hockey will not likely ever happen, even if it would be an effective way to diminish injuries. Body checking has been a part of competitive men's ice hockey since the beginning and is likely to remain so. (Darling et al. 2011.) Those in favor of body checking protest that the game demands it. They suppose that injuries result from incorrect given or taken body checks, and poor technique should not deter leagues from allowing body checking. In their opinion the focus should be on educating coaches and teaching body checking skills for players at all levels of ice hockey. (Marchie & Cusimano 2003.)

Apart from the amount of body checks and unintentional collisions, there are also many other risk factors affecting injury rates. The level of play (Darling et al. 2011; Emery & Meeuwisse 2006), player's age and size (Emery & Meeuwisse 2006), playing position (Björkheim et al. 1993; Emery et al. 2010; Flik et al. 2005) and playing time (Smith et al. 1997) as well as previous injuries (Emery et al. 2010) and musculoskeletal abnormalities (Smith et al. 19997), just to mention a few, may also have an effect on player's tendency to get injured.

2.4.4 Most common injuries

The most common body parts to be injured in ice hockey are knee/leg, head and shoulder (figure 7) (Flik et al. 2005). The most common type of injury has been reported to

be concussion in both men's and women's ice hockey (Agel et al. 2010), which will be discussed more in detail in the next paragraph. It is alarming that also among young players the concussions are the most common type of injuries accounting even more than 15 % of all injuries (Emery et al. 2010). For men shoulder and knee ligamentous injuries come after concussions, but among women the second most common injuries are hip/groin and ankle ligamentous injuries (Agel et al. 2010.)

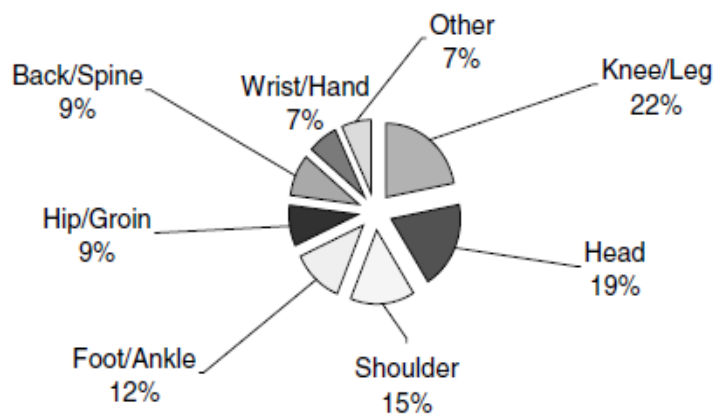


FIGURE 7. Injuries by body part (adapted from Flik et al. 2005).

3 CONCUSSIONS IN ICE HOCKEY

Sport related concussions did not receive much attention until the early 1990s. At that time the media and fans fostered a heightened awareness of sport concussions because of the high-profile athletes who attributed their retirements to repetitive concussions. (Powell 2001.) After that concussions have continued having more attention among sport medicine professionals year after year. Nowadays concussion is the most usual head injury seen among athletes (Bailes & Hudson 2001) and only in the United States around 300 000 sport-related concussions are reported every year (Covassin et al. 2008).

Sport concussion has been defined as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (Aubry et al. 2002). A direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head may often lead to cerebral concussion. Concussion commonly results in a rapid onset of short duration impairment of neurological function such as a loss of consciousness or balance problems. (Aubry et al. 2002.) Often impairment resolves spontaneously (Aubry et al. 2002), but in some cases post-concussive symptoms may be prolonged or persistent (McCrory et al. 2005).

Concussions occur almost in all sports but with different frequencies. In sports, in which many collisions take place, such as american football, boxing and ice hockey, the risk of a concussion is much more pronounced compared to non-collision sports like swimming and track and field. The nature of the game, the rules and regulations, the specific physical activities of the participants and the environmental conditions are associated with the amount of concussions. (Powell 2001.)

Ice hockey has one of the highest rates of concussions among contact sports (Flik et al. 2005). In ice hockey most often concussion occurs during the games (81%), because high collision speed is required to cause a concussion (Flik et al. 2005). It has been observed that younger players are more susceptible to concussions than older players. This may be a result of less playing experience, including more aggressive play, more illegal contact, and less realistic view of protective equipment. Also younger players might not

be as good skaters as the older ones and that may lead them to fall more frequently. (Hostetler et al. 2004.)

The position played is also an important factor in concussion susceptibility. Flik et al. (2005) reported that 76 % of the concussions are suffered by forwards and 24 % by defensemen. In their study goalies did not suffer any concussions. In proportion to number of players on the ice, forwards had 2.1 times as often concussions as the defensemen. (Flik et al. 2005.) In a Finnish study 9 concussions suffered in FNL during a season, 5 were sustained by goalkeepers and only 4 by other players (Mölsä et al. 1997). The contradictions in the findings between North America and Finland might be due to more physical style to play and smaller ice surfaces in North America, which place the forwards at higher risk for contact injuries (Flik et al. 2005).

3.1 Mechanisms causing concussion

The mechanisms underlying behind acute concussions are varied (Gwin et al. 2009). At impact the skull decelerates suddenly, but the brain's center of mass continues moving forward (Payly et al. 2006). The head does not only decelerate in unidirectional fashion, but also the head is accelerating in a new vector, often rotating backward and downward. Changes in various acceleration vectors makes it complicated to sum the forces brought to bear on the brain (Barth et al. 2001) and, thereby, the relationship between skull motion and brain deformation are not yet understood by details (Payly et al. 2006).

In so called coup injury, the brain strikes against the inner skull in the direction the athlete was initially travelling. That happens due to the force in the opposite velocity vector. In countercoup injury the brain "rebounds" from the direction of the deceleration and runs against the inner lining of the skull in the opposite direction. When rotational forces are directed to the brain, the locations at which the brain may contact the inner lining of the skull are various. (Barth et al. 2001.) The strike of the brain with the inner skull leads to rapid deformation of brain tissue, which is thought to be related to subse-

quent pathology. It is believed that the rapid deformation can cause even axonal injuries and cell deaths in brain. (Payly et al. 2006.)

The magnitude of acceleration, at which concussions occur, is not exactly known. It has been suggested that head impact with the acceleration more than 200 Gs is related to a serious brain injury. These kinds of results have been measured in animal studies as well as in human deceleration experiments. (Naunheim et al. 2003.) The fact that, there are nearly always numerous directions of forces that might influence in the outcome makes it complicated to investigate (Barth et al. 2001).

Important impact characteristics determining whether concussion occurs or not include peak linear acceleration, peak rotational acceleration, impact duration, impact location, and a combination of these variables. (Gwin et al. 2009.) It is known that, when the impact duration increases, the acceleration obviously decreases (Naunheim et al. 2003). According to Newton's 2nd law, $F = ma$, in which a is change in velocity over time and m refers to mass, it can be figured out that lower accelerations lead to lower forces and, thus, to lower risk of concussion. Also the location, at which the impact takes place, has an effect on the risk of concussion. If an athlete's upper body collides with other athlete's lower body, there is long deceleration distance and time diminishing the applied force in the brain, which results in lower injury risk. (Barth et al. 2001.)

Anticipation also plays an important role when talking about concussion risk. When both athletes are anticipating the collision, they appropriately align their bodies and/or tense their neck muscle. When the athletes are unaware of an impact, they may experience a whiplash-type force, which means, that the created torque is seen as rotation of the head in or out of its original plane. (Barth et al. 2001.)

In ice hockey the high accelerations directed to the head are often related to collisions with other players or the boards (Naunheim et al. 2000). Contact with another player is a reason of concussion almost in two thirds of all concussions in ice hockey. Contact with board or glass, instead, explains approximately one fourth of the concussions suffered (figure 8). (Agel et al. 2007.)

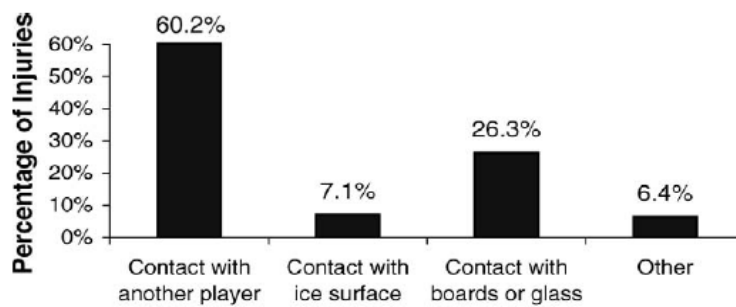


FIGURE 8. Game concussion injury mechanisms in men's ice hockey (n = 422) (Adapted from Agel et al. 2007).

3.2 Symptoms, signs and classification

Concussion is often followed by a graded set of clinical symptoms (table 1) (McCrary et al. 2005), which may be somatic, cognitive and/or emotional. Sometimes physical signs can be presented too. (McCrary et al. 2009.) Sequence of low-level injuries may lead to chronic neurologic sequelae (Naunheim et al. 2000) and the athletes with previous concussions seem to have significantly more symptoms (Iverson et al. 2004) as well as poorer neurocognitive function after concussion compared to the first-timers (Covassin et al 2008; Iverson et al. 2004).

TABLE 1. Most common signs and symptoms of acute concussion (adapted from McCrary et al. 2009.)

Cognitive features	Typical symptoms	Physical signs
Unaware of period, opposition or score of game, confusion, amnesia, loss of consciousness	Headache or pressure in the head, balance problems or dizziness, nausea, feeling "dinged" or "foggy", visual and/or hearing problems, irritability or emotional changes	Loss of consciousness or impaired conscious state, poor coordination or balance, concussive convulsion, gait unsteadiness, poor concentration, displaying inappropriate emotions, vomiting, vacant stare, slurred speech, personality changes etc.

During the last decades plenty of different kind of classifications for concussions has been published. According to the International Conference on Concussion in Sport

(2008 & 2004) concussions are classified as either a simple or a complex concussion. Around 80 to 90 % of all concussions are categorized as a simple concussion (McCrory et al. 2009). In those cases the symptoms resolve without any complications in 7 to 10 days postinjury. In that kind of concussions the best treatment is rest until all symptoms have passed. In complex concussion the symptoms, instead, are persistent. Athletes may have prolonged cognitive impairment or loss of consciousness as well as specific sequelae. Normally neurophysiologic testing and other investigations must be done in pursuance of complex concussion. (McCrory et al. 2005.) In other types of classifications concussions are often categorized into three grades: mild, moderate and severe concussion (table 2). (Lippincot & Lippincot 1997.)

TABLE 2. Classification of concussion (adapted from Lippincot & Lippincot 1997).

	Mild concussion	Moderate concussion	Severe concussion
Symptoms	Brief confusion or mental status alterations, not loss of consciousness	Symptoms last over 15 minutes, not loss of consciousness	loss of consciousness

3.3 Prevention

The incidence and severity of ice hockey related concussions as well as the costs of treatments are increasing (Biasca et al.2002), thus, something should be done. Equipment development, rule enforcement, and instructions on how to give and receive body checks play an important role in reducing the amount of concussions (Smith et al 1997). In addition, modifying or developing playing environment can serve to reduce concussion rate. It is also important that medical doctors regularly evaluate and analyze the injury databases in order to detect the potential risk factors and identify the causal relationships (Biasca et al. 2002). However, the extraordinary nature and characteristics of ice hockey make concussion prevention a challenge, because there are high-velocity impacts with players, pucks, sticks, ice surface, and boards occurring in every single game and practice. (Agel et al. 2007.)

Rule enforcement. Only a small amount of player-to-player contacts, which lead to injury, leads up to punish the other player. According to the study of Mölsä et al. (2000) only in 11 % of the cases the injury was caused by breaches of the rules. In the assessment of the recording physician present at the games, foul style of play gave rise to 22 % of all injuries. (Mölsä et al. 2000.) Therefore, there might be a request for more referees in all games (Björkheim et al. 1993), which could make it easier for them to see all the fouls done on the rink. Referees also should enforce the hockey rules and punish more strictly especially in head checks, high sticks, and checks from behind (Biasca et al. 2002), which are the most common illegal causes of injuries.

Equipment. Ice hockey requires specialized equipment to protect players from each other, the ice, boards, goalposts, skates, pucks, and sticks (Flik et al. 2005). The improvement of equipment has increased during the last decades, but still, the amount of injuries is multiplying. This might be owing to the increased quality and quantity of protective equipment, which makes the players to feel “safety” leading to increase in violence and more aggressive behavior in a game. (Mölsä et al. 2000.)

Equipment seems to be effective at preventing specific types of injuries. In every session there are contacts with puck and sticks, but still, they represent only 7.0 % and 6.4 % of all injuries, respectively. Based on this finding it is obvious that hockey equipment is effective in dissipating the forces applied with sticks and puck. The increasing amount of injuries, in particular concussions, due to a collision with other players, the boards, or the ice, instead, shows us, that the equipment is probably less effective to dissipate forces when the collision occurs (Agel et al. 2007). Thus, it is evident that the development of protective equipment continues (Mölsä et al. 1997).

Helmets give partial protection for athletes against concussions. Helmets attenuate impact due to the deformation of a compliant, energy absorbent layer, which can be seen as energy dissipation. (Naunheim et al. 2003.) The cushioning influence of helmets also increases the distance of deceleration and, thereby, diminishes the forces directed to the brain. When using the helmets, the impact force is applied over a greater surface area. From the physics formula $P = F / A$, in which P indicates pressure, F is the force applied and A refers to the area to which the force is applied, it can be seen that greater area in

which the force is applied leads to lower pressure in the brain. (Barth et al. 2001.) The mass of the helmet, instead, will diminish the velocity imparted upon the person's head, thus, reducing the acceleration of the head. The compliant soft layer inside the helmet also reduces the head acceleration by increasing the time involved in the momentum transfer. (Naunheim et al. 2003.) Therefore, the use of helmet protects the athlete from concussion in many different ways, when using it properly (Biasca et al. 2002).

Adequate wearing of the visor or full facemask, and mandatory use of a custom made mouthguards may reduce the amount of concussions too. Properly fitted mouthguards dissipate forces directed to the full facemask (figure 9) and, thus, by using them the incidence and severity of concussions become lower. (Biasca et al. 2002.) Also the cushioning effect of the mouthguards gives protection against concussions by increasing the time and the distance of deceleration (Barth et al. 2001).

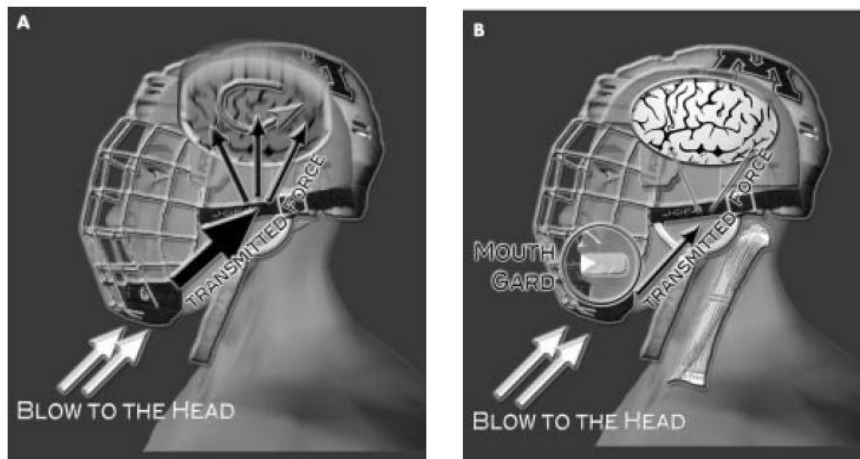


FIGURE 9. Proper use of mouthguards absorbs the energy caused by an impact to the full facemask and, thus, reduce the amount and severity of concussions (Adapted from Biasca et al. 2002).

Education. Education has an important role in reducing ice hockey related injuries such as concussions. Better education must be given not only to players, coaches and trainers, but also to managers, referees, equipment manufacturers, national sport associations, and doctors. The players should be educated to respect their opponents and to be aware of the hazards of their actions. (Biasca et al. 2002.) They also should learn the correct technique of giving and taking body checks, because unexpected blows or

changes in velocity of the head often result in the greatest forces in the brain (Barth et al. 2001). It is also vital that the players can differentiate between aggressive and assertive checking behavior, the first one having intent to injure, and the second one trying to take the player off the puck (Smith et al. 1997). Apart from that the education relating to the proper way to wear the equipment plays an important role too (Biasca et al. 2002).

Playing environment. One effective way to diminish the amount of concussions caused by body contact with another player near the boards would be the modification of playing environment, which gives an opportunity to affect impact characteristics. Nowadays diversified selection of element and glass types installed in ice rinks exists (Agel et al. 2007), but it is not yet well understood how different dasher board structures and materials affect impact characteristics and, thereby, concussion risk.

4 IMPACT CHARACTERISTICS

Impact is a high force or acceleration applied over a short time of period when two or more objects collide. The basic idea of a collision is that the motion of the colliding objects, or at least one of them, changes remarkably and a clear separation of times that are “before the collision” and “after the collision” can be done. (Resnick et al. 1992, p. 207)

Impacts are commonly classified according to whether or not kinetic energy is conserved at impact. The collision is said to be an elastic collision when the kinetic energy is observed. Otherwise, the collision is classified to be inelastic. The only elastic collisions known to happen are those occurring between atomic, nuclear, and fundamental particles. All other collisions are always inelastic to some extent even if some of them might be treated as elastic collisions. In an inelastic collision deformation of the colliding objects absorb most of the force of the collision. According to the law of conservation of total energy, the kinetic energy of the projectiles is transformed into heat, sound energy and potential energy of the deformation. Impact characteristics depend on the colliding materials as well as on the velocity, direction and mass of the objects colliding. (Resnick et al. 1992, p. 211-214.)

When investigating impact characteristics, many biomechanical variables must be measured to understand the overall impact responses. Linear and rotational accelerations are important variables in defining the outcome of an impact. Apart from those variables, the researchers are often interested in peak force, impact impulse and impact duration as well as jerk (Broglia et al. 2009), impact velocity or changes in movement (Hendersson & Hoyes 2009) during the collision. In many cases impact attenuation (Dufek et al. 2008) or energy absorption must be taken into account too, when evaluating impact characteristics (Marino & Potwin 2002). In addition impact location and impact magnitude are also important factors (Broglia et al. 2009). All these variables describing impact characteristics can be measured by using different kind of biomechanical methods such as accelerometers (Broglia et al. 2009), high speed filming (MacNeill & Kirkpatrick 2002) and force transducers (Burkhart & Andrews 2010).

5 MANUSCRIPT

5.1 Introduction

Ice hockey is played in many countries throughout the world (Flik et al. 2005), but it is especially popular in northern and eastern parts of Europe and in North America (Mölsä et al. 1999). At the elite level the ice hockey players are highly conditioned athletes with a combination of strength, agility, balance, skill, and controlled aggression (Flik et al. 2005).

The game of ice hockey is played on a white ice surface known as a rink (International ice hockey federation, 2010b). Nowadays there is diversified selection of ice hockey rinks having differences in the element and the protective shielding materials and structures (Agel et al. 2007). Dasher boards used in indoor applications are most often either aluminum- or steel-framed (Audas 2009) and the puck board is usually made of plastic or wood (International ice hockey federation, 2010b). As a protective shielding material, tempered glass, acryl and polycarbonate are most commonly used.

There are many challenges when constructing ice hockey arena dasher boards. Apart from players' and spectators' safety, the boards must be also long lasting and give spectators a good viewing experience. When selecting the proper board design, the type of hockey to be played, other ice sports, spectators seating, and required portability, just to mention a few, must be also taken into account. (Coleman & Sutherland 2007.) Through design and testing the best combination can be found for each ice hockey rink (Milton et al. 2002).

The game itself induces a great risk for injury because it combines high speeds with aggressive physical play (Flik et al. 2005) and the players have become bigger, faster and stronger (Biasca et al. 2002). The overall injury rate is around 5 injuries per 1000 athletic exposures (AEs) (Flik et al. 2005) and the injuries are much more common to occur during games than practices. Agel & Harvey (2010) reported that in Canada the

average injury rate for men during practice was 2.23 injuries per 1000 AEs and in games the comparable rate was as high as 18.68 per 1000 AEs. In Finland, according to Mölsä et al. (2000), 75 % of the injuries occurred during the games and 25 % during the practices.

According to many studies, contact with another player, being unintentional collision or body checking, is the most common cause for an ice hockey injury (Darling et al. 2011; Mölsä et al. 2000). It has been shown that as much as 50 % of injuries occurring during games are related to direct contact with another player or his/her equipment (Agel et al. 2007). Most often injuries are reported by the player receiving the body check and only few, approximately 16 % of those body checks, results in a penalty. Apart from player-to-player contact injuries, also environmental contact injuries and no contact injuries do occur. (Emery& meeuwisse 2006).

It has been shown that there is an absolute injury risk reduction, when body checking is not allowed. The reduction has demonstrated to be as high as 2.84 injuries per 1000 player-hours. The risk of severe injuries, concussions and severe concussions has noted to diminish by 0.72, 1.08 and 0.20 injuries per 1000 player-hours, respectively. (Emery et al. 2010.) Thereby, removing body checking totally from ice hockey would serve to reduce the amount of injuries, especially the severe ones, but body checking has been a part of competitive men's ice hockey since the beginning and is likely to remain so. (Darling et al. 2011.) Thus, other ways to affect the amount of injuries must be investigated.

The most common body parts to be injured are knee/leg, head and shoulder (Flik et al. 2005) and the most common type of injury has been reported to be concussion (Agel et al. 2010). High accelerations directed to the head cause concussions, which are about two thirds of all injuries related to contact with another player. Contact with dasher board, instead, explains approximately one fourth of the concussions suffered. (Agel et al. 2007.)

During the last years the incidence and severity of ice hockey related concussions as well as the costs of treatments have been increasing (Biasca et al.2002) and, hence,

something should be done to stop this growth. Equipment development, rule enforcement, and instructions on how to give and receive body checks are important in reducing the amount of concussions (Smith et al 1997). In addition, modifying and developing playing environment can serve to reduce concussion rate by affecting impact characteristics.

Therefore, the aim of this study was to examine how dasher board materials and structures affect impact characteristics and, thereby, the risk of concussions. The main research problems were to find out the differences in impact characteristics between three different ice hockey arena dasher boards, reveal how pronounced the differences are and expand understanding of what explains them. In addition, it was of interest to study how much impact characteristics differ between different impact locations of protective shielding. Also a comparison of impact characteristics of single- and dual-framed dasher boards was realized to find out what effects the frame type has on element stiffness. An effect of protective shielding mass on element stiffness was also studied.

5.2 Methods

The measurements of this study were divided into two parts. In the first part the physiological characteristics of body checks in men's elite level were determined in real game measurements. The second part consisted of simulation of body checks in the laboratory.

5.2.1 Real game measurements

Data collection. In the first part 5 games of Finnish National Hockey League and 2 playoff games of the second highest ice hockey league in Finland were observed. By experience it was expected that the most body checks take place in the corners of the rink. Thereby, two protective shieldings in one corner of the rink were chosen as the measurement area. One high speed camera (Sony NX5, Sony Corporation, Tokyo, Japan) was located in the roof of the ice hockey arena to image an area of 3 x 4 meters from the chosen corner (figure 10). The recording was done at the rate of 250 Hz by using a 3 seconds pretrigger, which allowed us to start recording after a body check had occurred. The calibration was done by knowing the distances between the lines in ice. High speed filming was used to record data for a two dimensional movement analysis from body checks. In addition a "visual camera" (Sony HDR-HC5, Sony Corporation, Tokyo, Japan) was used to film the body checks from the horizontal view at the rate of 250 Hz.

Apart from the high speed filming, also accelerometers (MMA2301, Freescale Semiconductor Inc, USA) were used to collect data. There were 4 accelerometers located in the protective shielding 30 centimeters above the junction between the element and the protective shielding and 30 centimeters from the gap between two protective sheets (figure 10). Two accelerometers were positioned in each of the two protective shieldings. The amplification for the accelerometers was $1\text{ V} = 100\text{ G}$. The data was collected at the rate of 1000 Hz using 3 seconds pretrigger and Signal –software (Signal version 2.16, Cambridge Electronic Design, Cambridge, UK).

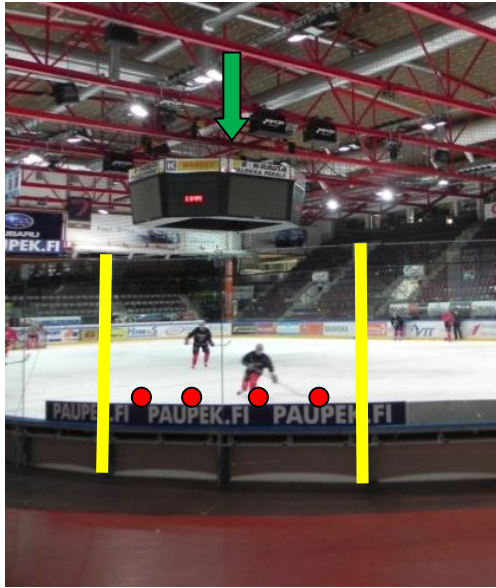


FIGURE 10. Measurement arrangement. Yellow lines indicate the observation area, green arrow shows the position of high speed camera and red circles represent the location of accelerometers (Photograph by Juha Isolehto).

Data analysis. All 17 body checks occurring at the observation zone were taken into account, but later 6 of them were eliminated due to missed or unclear data or intangibility; finally 11 body checks were analyzed. The high speed camera data was processed by Vicon Motus Motion Analysis System (Vicon Motus version 8.5, Vicon, Oxford, UK). To perceive the players' horizontal velocity and direction, their shoulder line and head were digitized at the rate of 250 Hz. The velocities were used to define the mass of the pendulum.

From the accelerometer data the peak acceleration value directed towards the protective shielding during each of the body checks was determined. The acceleration value was detected from the accelerometer in which the colliding players hit closest, and if the accelerometer was not possible to be sorted out, the body check was eliminated from the analyses. Analyses were realized in Signal –software (Signal version 2.16, Cambridge Electronic Design, Cambridge, UK).

Based on the results, acceleration values directed towards protective shielding were defined for the “common”, “hard but legal” and “hard illegal” body checks, which are referred later as slow, medium and fast velocity impacts, respectively. Acceleration val-

ue of slow velocity impact was the average acceleration value of body checks analyzed. Because all the body checks observed were legal ones, the acceleration value of medium velocity impact equals to the highest acceleration value recorded in the real game measurements. The acceleration value for fast velocity impact, instead, was an approximation based on the acceleration values known for the two other body check types. Slow, medium and fast velocity impacts were perceived to cause an acceleration of 5 g, 15 g and 25 g, respectively, towards protective shielding.

5.2.3 Simulation of body checks in the laboratory

Pendulum system. In the second part of the study the simulation of body checks was done in the laboratory where a pendulum system was constructed (figure 11). The weight of the pendulum was set on 60 kg and the weight was kept constant throughout the whole measurement protocol. With a pendulum weighing 60 kg, the acceleration responses as well as the impact velocities were corresponding to the values measured in the first part of the study. Thereby, 60 kg is presumed to be near the average weight colliding with dasher board at body checks in men's elite level ice hockey.



FIGURE 11. Pendulum system (Photograph by Tuomo Hyvärinen).

The pendulum system was attached to the roof elements and its swinging was controlled by a winch. Hard and rigid impact surface was covered with 20 mm thick protective padding (Cellrubber CR Neopren with a density of $0.13 - 0.17 \text{ g / cm}^3$, Etra). The height, in which the pendulum hit the dasher board, was adjustable. Two different im-

impact heights were chosen. One of them was in protective shielding at the height of 30 cm being approximately equal to players' shoulder height. Another impact location was at the uppermost part of the element corresponding to players' hip height.

Three different impact velocities, which were matched with the acceleration responses of "common", "hard but legal" and "hard illegal" body checks, were used. The matching was done by the acceleration values impacting on the reference dasher board, which was comparable with the dasher board measured in real game measurements; dasher board materials, anchoring system and inter-shielding supports were equivalent. The matching was done in comparable location of the dasher board as the data collection in the real game measurements. Pendulum's dropping height was standardized for each impact velocity by a winch keeping the impact velocities constant throughout the whole procedure. Pendulum had a velocity of 1.33 ± 0.08 m/s, 2.54 ± 0.10 m/s and 3.37 ± 0.13 m/s in slow, medium and fast velocity impacts, respectively.

Measurement protocol. There were five different dasher boards in the laboratory tests (table 3) (RAI-TA SPORT Co. Ltd, Oulainen, Finland). The dasher boards were anchored to the base slab on the floor of the laboratory with real anchoring system and special posts were located at both ends of the dasher board to support it (figure 12). Due to the willingness of measuring the same dasher boards, which are sold to the clients, the width of the reference dasher board elements differed from the width of the other dasher board elements. Straight and corner elements of the reference dasher board were 300 cm and 276 cm wide, respectively. The comparable widths of other dasher board elements were 240 cm and 222.5 cm, respectively.



FIGURE 12. Anchoring system (left) and special posts located at both ends of the dasher board to support it (right). (Photographs by Tuomo Hyvärinen)

TABLE 3. Tested dasher boards.

ELEMENT TYPE			PROTECTIVE SHIELDING			
			Material	Thick-ness	Pockets	Inter-shielding support
Reference board	dasher	Dual-frame	Tempered glass	12 mm		Clips (polycarbonate)
Dasher board A		Single frame	Tempered glass	12 mm	Rubber surfaced	Clips (polycarbonate)
Dasher board B		Single frame	Acryl	15 mm	Plastic surfaced	Long H-list
Dasher board C		Single frame	Tempered glass	12 mm		Aluminum posts
Dasher board D		Single frame	Polycarbonate	8 mm		Aluminum posts

There were 10 impact locations in each dasher board (figures 13 and 14). The values recorded from the impacts at protective shielding (impact locations 1, 2 and 3 as well as 6, 7 and 8 in figures 13 and 14) were used to demonstrate the differences in impact characteristics between different dasher boards and different impact locations. The impacts directed to the element (impact locations 4 and 5 as well as 9 and 10 in figures 13 and 14) were given because of an aspiration to compare impact characteristics of single- and dual-framed dasher boards and to show the effects of protective shielding mass on element stiffness. Altogether 15 impacts, which consisted of five slow impacts, five medium impacts and five hard impacts, were given in each location. Impacts were never given to the outermost element.

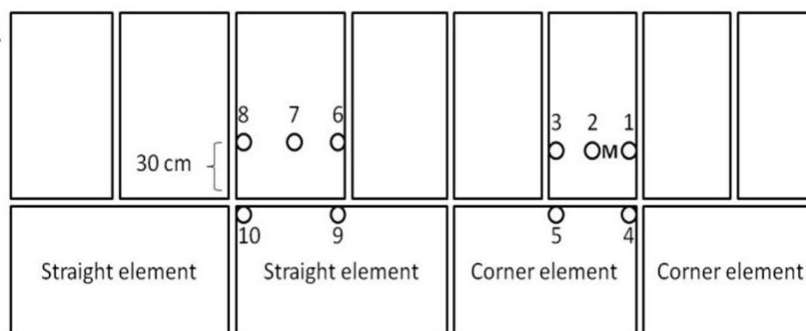


FIGURE 13. Impact locations in the reference dasher board as well as the dasher boards A and B. O = impact location, M = matching point in reference dasher board.

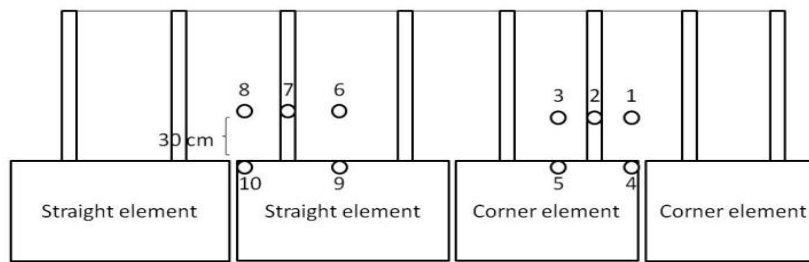


FIGURE14. Impact locations in the dasher boards C and D. O = impact location

In the reference dasher board and the dasher boards A and B, the impact locations at protective shielding and element were both divided into two categories; impacts at the straight part of the dasher board and impacts at the corner part of the dasher board (table 4). The results are presented as average values of impacts at the straight and the corner part of the dasher board.

TABLE 4. Classification, which is used in result section, of impact locations of reference dasher board as well as dasher boards A and B.

	Impacts at straight part of dasher board		Impacts at corner part of dasher board	
	Protective shielding	Element	Protective shielding	Element
Impact locations	6, 7 and 8	9 and 10	1, 2 and 3	4 and 5

The data from the dasher boards B, C and D was taken into account when analyzing the consistency of protective shielding. The consistency was analyzed in order to know how pronounced the differences in impact characteristics are between impacts given at protective shielding and long H-lists or shielding supporting posts. The results are presented as average values of impacts at the straight and the corner part of the dasher board (table 5). In the dasher boards C and D the shielding supporting posts were not clocked into the frame and, therefore, they may have slightly elevated. Due to this, the absolute values are not presented in the result section.

Data collection. All impacts were recorded by using two high speed cameras (Fastec Inline, Fastec Imaging Corporation, San Diego, California, USA). One camera, which was located perpendicular to the impact direction, was filming the pendulum, in which one reflective marker was located. The camera was calibrated by using a calibration framework with four reflecting markers in known distances. Another camera was also

TABLE 5. Classification, which is used in result section, of impact locations of the dasher boards B, C and D.

		Impacts at straight part of dasher board		Impacts at corner part of dasher board	
		Protective shielding	Long H-list / Shielding supporting post	Protective shielding	Long H-list /Shielding supporting post
Impact locations in dasher board B	7	6 and 8	2	1 and 3	
Impact locations in dasher boards C and D	6 and 8	7	1 and 3	2	

placed perpendicular to the impact direction, but it was set behind the dasher board. There were four reflective markers located in the backside of the dasher board; one in the element and others at the heights of 0 cm, 30 cm and 60 cm in the protective shielding. Recording with both cameras was done at the rate of 250 Hz and 3 seconds pretrigger was used. There were three extra lights enhancing the reflection of the markers.

An accelerometer (MMA2301, Freescale Semiconductor Inc, USA) was located on the backside of the dasher board / long H-list / shielding supporting post coinciding with impact location (figure 15). In the dasher board B the long H-list was at an angle from backside, so small hole into the H-list was done to locate the accelerometer into plateau (figure 15). The recording was done at the rate of 1000 Hz using 3 seconds pretrigger and the data was collected by Signal –software (Signal version 2.16, Cambridge Electronic Design, Cambridge, UK). Both cameras and the accelerometer were synchronized to start recording from the same signal.

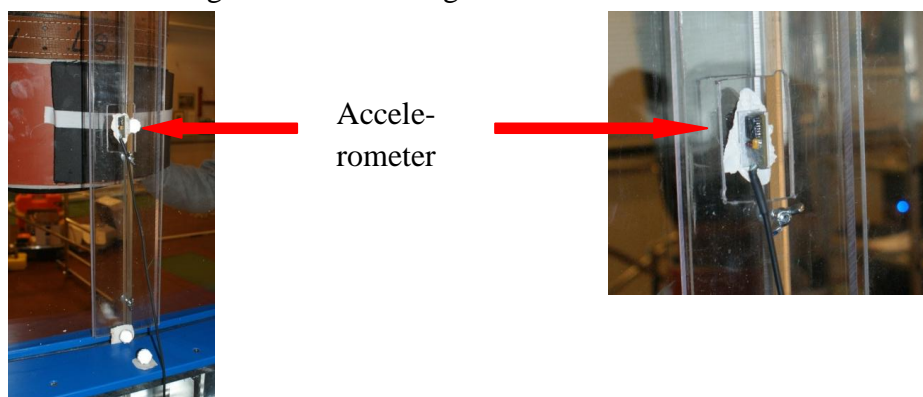


FIGURE 15. Location of accelerometer in the dasher board B (Photographs by Tuomo Hyvärinen).

Data analysis. The high speed camera data was processed by Vicon Motus Motion Analysis System (Vicon Motus version 8.5, Vicon, Oxford, UK). To perceive the pendulum's velocity and acceleration, the marker located in the pendulum was digitized with automatic tracking. From another camera with backside view of the dasher board all four markers were digitized with automatic tracking to detect stopping distances of the element and the protective shielding at the height of 30 cm and 60 cm. The digitizing was done at the rate of 250 Hz.

The values for four dependent variables; peak force, stopping distance, stiffness, and energy absorption, were calculated in Excel (Microsoft Office Excel 2007, Microsoft Corporation). Peak force was defined by Newton's 2nd Law: $F = ma$, where the mass was constant and known (60 kg) and the peak acceleration was calculated from the digitized data. Stopping distance was determined as the difference between the starting coordinates of a certain marker and the maximum point in which that marker hit during an impact (figure 16). Stiffness values for the protective shielding and the element were calculated by following formulas: $\text{Stiffness}_{\text{protective shielding}} = F_{\text{peak}} / \text{Stopping distance}_{30\text{cm}}$ and $\text{Stiffness}_{\text{element}} = F_{\text{peak}} / \text{Stopping distance}_{\text{element}}$. Kinetic energy of the pendulum was determined before and after an impact by using a formula of $E_{\text{kin}} = \frac{1}{2} mv^2$, in which mass was constant and known (60 kg) and horizontal velocity was defined from the digitized data. Energy absorption was calculated as the ratio between kinetic energy before and after an impact and the following formula was used: $E_{\text{abs}} = (E_{\text{kin_pre}} - E_{\text{kin_post}}) / E_{\text{kin_pre}}$. Average values for slow, medium and fast velocity impacts were calculated for each dependent variable in each impact location. Later the average values for slow, medium and fast velocity impacts at the straight and the corner part of the dasher board were defined.

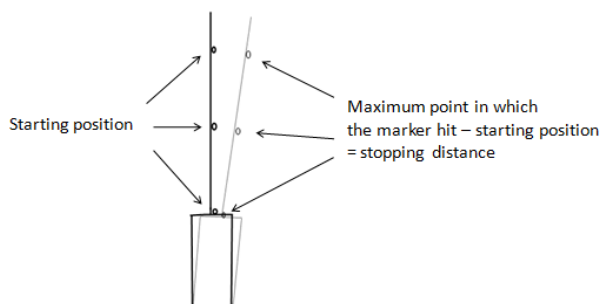


FIGURE 16. Definition of stopping distance.

Statistics. Differences in impact characteristics between the reference dasher board and the dasher boards A and B were assessed using Univariate analysis of variance (UNIANOVA) and Tukey's post hoc –test. The consistency of protective shielding was tested with independent samples T-test. Independent samples T-tests were also used to evaluate the effects of element type and protective shielding mass on element stiffness. Differences were considered significant at the level of $p < .05$. All statistics were computed in SPSS-software (SPSS PASW Statistics 18, Chicago, USA).

Repeatability. Before starting the simulation of body checks the repeatability was tested. Altogether 15 slow, 15 medium and 15 fast velocity impacts were given to the matching point in the reference dasher board. All the impacts were recorded by high speed cameras as explained earlier and also the acceleration data was collected. Due to the missed data, 5 slow velocity impacts and 2 medium velocity impacts were not included into the analyses. The marker located in the pendulum was digitized by Vicon Motus Motion Analysis System (Vicon Motus version 8.5, Vicon, Oxford, UK) to detect acceleration of the pendulum. Repeatability was assessed by Intra Class Correlation (model: two-way random, type: absolute agreements) from the deceleration phase of each impact and it was computed in SPSS –software (SPSS PASW Statistics 18, Chicago, USA).

The peak acceleration value for slow, medium and fast velocity impacts was $38.19 \pm 0.90 \text{ m/s}^2$, $76.30 \pm 0.71 \text{ m/s}^2$ and $99.70 \pm 1.73 \text{ m/s}^2$, respectively. Intra Class Correlations for slow, medium and fast velocity impacts were statistically significant ($p < .05$) reaching values of 0.994, 0.997 and 0.997, respectively. Values in Inter Item Correlation Matrix varied between 0.991 and 1.000. In the light of these findings the method used can be said to be repeatable and, thereby, the method is expected to be reliable.

5.3 Results

5.3.1 Comparison of impact characteristics of three different dasher boards

Differences in peak forces between impacts given in the reference dasher board and the dasher board A were statistically significant only in the straight part of the dasher board with slow and medium velocity impacts reference dasher board leading to higher peak forces ($p < .05$) (figure 17A). Instead, peak forces observed from impacts given in the dasher board B were significantly lower than the peak forces recorded from the reference dasher board and the dasher board A with all impact velocities in the straight as well as in the corner part of the dasher board ($p < .05$) (figure 17).

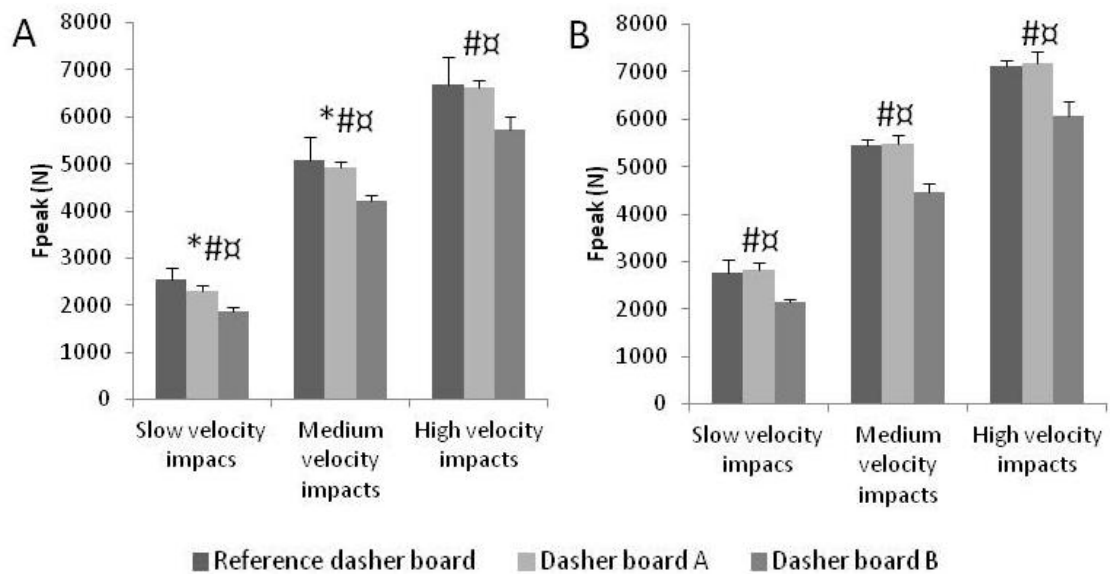


FIGURE 17. Peak forces when impacting at the straight part (A) and the corner part (B) of protective shielding.

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

Stopping distances of an element in the straight part of the dasher board varied widely depending on materials and structures of the dasher board. There were statistically significant differences in stopping distances with all impact velocities between all dasher boards in the straight part the dasher board the dasher board B resulting in the longest

stopping distances and the reference dasher board in the shortest ones ($p < .05$) (figure 18A). In the corner part of the dasher board the differences in stopping distances of an element were not as pronounced as in the straight part, but, however, some of them reached the level of statistical significance ($p < .05$) (figure 18B).

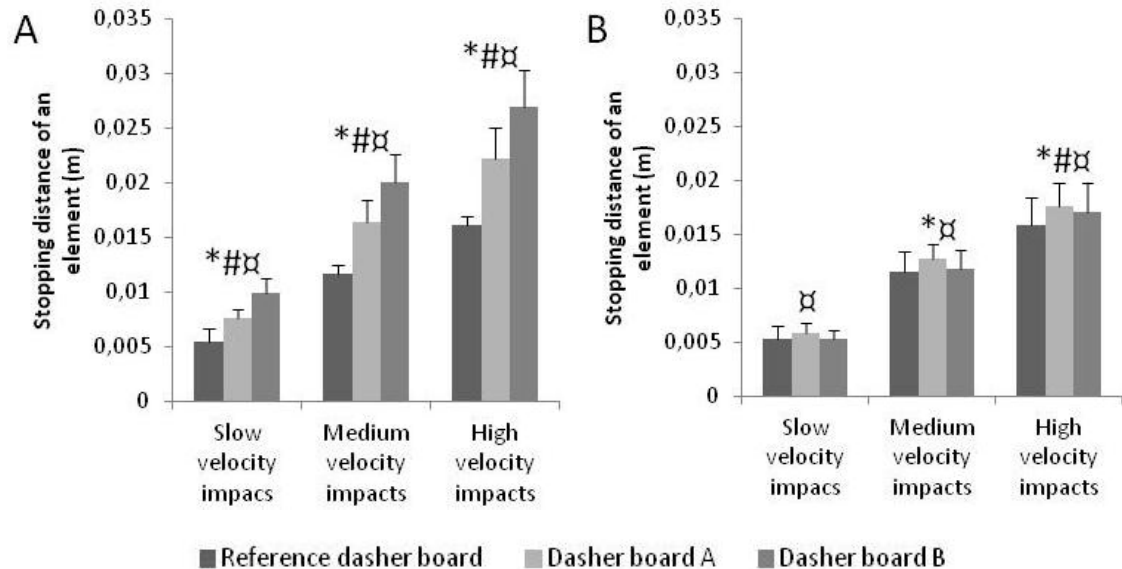


FIGURE 18. Stopping distance of an element when impacting at the straight part (A) and the corner part (B) of the protective shielding.

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

At the height of 30 cm and 60 cm of protective shielding the differences in stopping distances between different dasher boards were statistically significant with all impact velocities in the straight and the corner part of the dasher board ($p < .05$) (figure 19 and 20). The dasher board B led to the longest stopping distances, whereas, the reference dasher board resulted in the shortest ones.

Stiffness values between different dasher boards differed statistically significantly with all impact velocities in the straight and the corner part of the dasher board ($p < .05$) (figure 21). The reference dasher board was 161 % and 128 % stiffer than the dasher board B in the straight and the corner part of the dasher board, respectively, whereas, between the reference dasher board and the dasher board A the differences were not as

great. The reference dasher board was 23 % and 18 % stiffer than the dasher board A in the straight and the corner part of the dasher board, respectively.

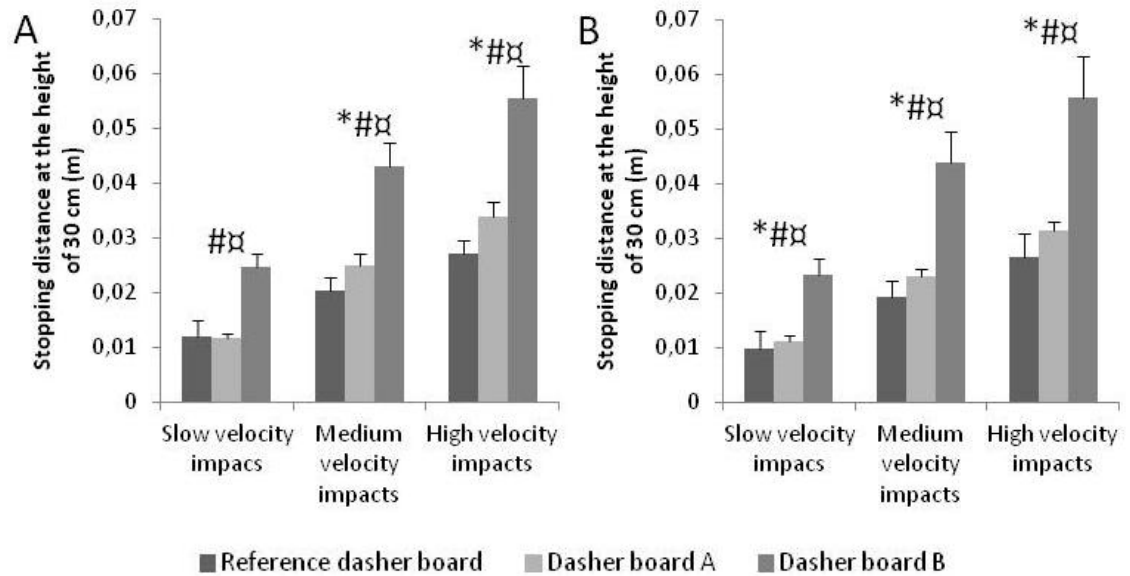


FIGURE 19. Stopping distance of protective shielding at the height of 30 cm when impacting at the straight part (A) and the corner part (B) of the protective shielding

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

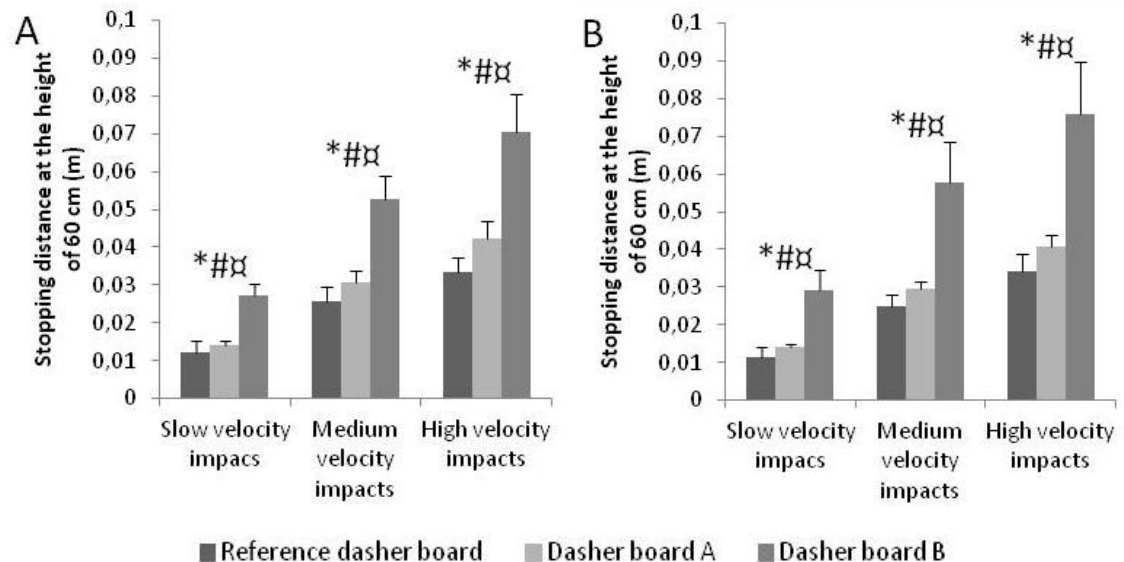


FIGURE 20. Stopping distance of protective shielding at the height of 60 cm when impacting at the straight part (A) and the corner part (B) of the protective shielding.

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

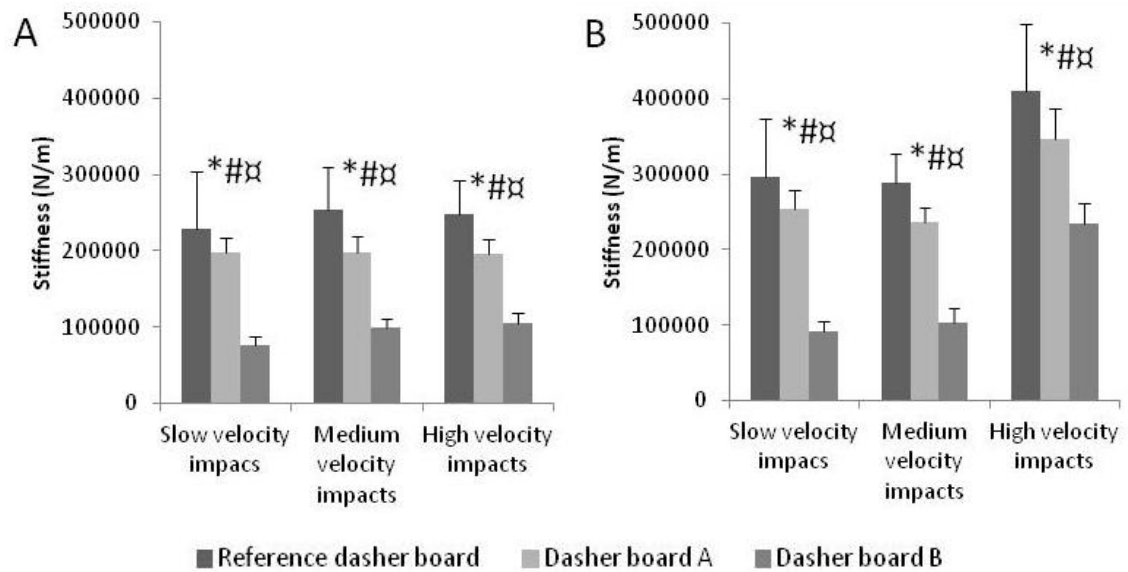


FIGURE 21. Stiffness of protective shielding when impacting at the straight (A) and the corner (B) part of the dasher board.

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

Energy absorption reflects the amount of energy being lost by the deformation of dasher board and colliding object as well as by heat and sound energy. The differences in energy absorption values among observed dasher boards were not great, but they reached statistical significance in some cases ($p < .05$) (figure 22). In the straight part of the dasher board the reference dasher board had the lowest capacity to absorb energy ($p < .05$). The ability to absorb energy between the dasher board A and the dasher board B differed significantly only with slow velocity impacts the dasher board A leading to higher energy absorption ($p < .05$). In the corner part the differences in energy absorption values were significant between the different dasher boards with slow and fast velocity impacts. With medium velocity impacts the energy absorption value of the dasher board A from the values of other dasher boards, but the reference dasher board and the dasher board B did not have significant difference in the ability to absorb energy ($p < .05$).

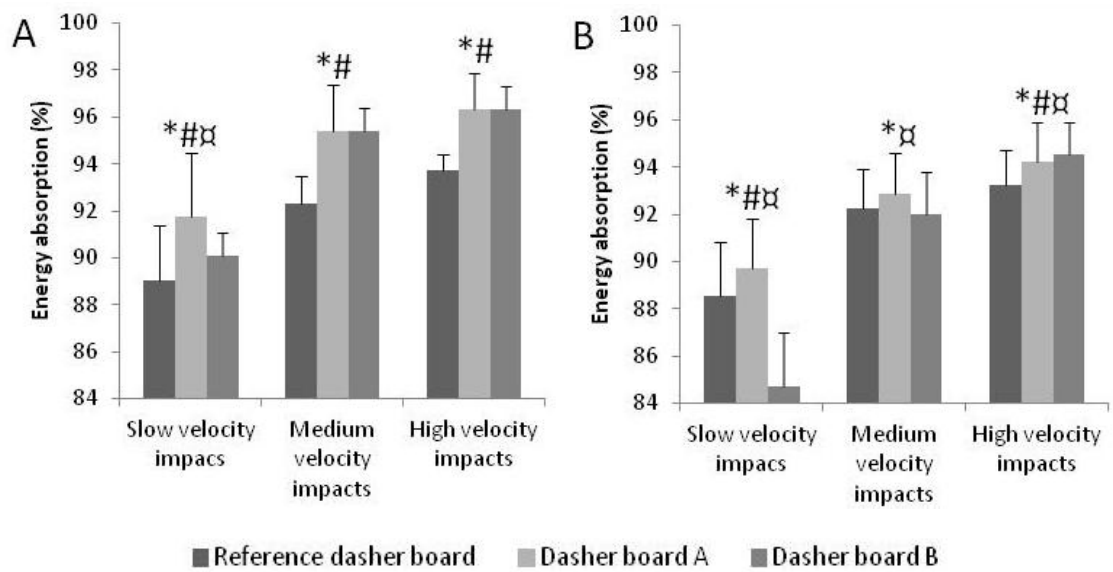


FIGURE 22. Energy absorption when impacting in the straight part (A) and the corner part (B) of the protective shielding.

* # α Statistically significant difference between reference dasher board and dasher board A, reference dasher board and dasher board B, dasher board A and dasher board B, respectively ($p < .05$).

5.3.3 Effects of impact location on impact characteristics

Impact characteristics between impacts given at protective shielding and shielding supporting posts or long H-lists were compared to find out how consistent different dasher board structures are. In the dasher board C impact location affected significantly peak forces with all impact velocities in the straight part of the dasher board so that impacts directed to the shielding supporting posts resulted in significantly higher peak forces ($p < .05$) (figure 23A). In the corner part the effect of impact location was significant only when medium velocity impacts were given ($p < .05$) (figure 23B). In the dasher board D the impacts directed to the shielding supporting posts led to significantly higher peak forces with all impact velocities in the straight and the corner part of the dasher board ($p < .05$) (figure 23C and D). In the dasher board B the differences in peak forces between impacts given at long H-lists and protective shielding were statistically significant with slow velocity impacts in the straight part of the dasher board and with medium and fast velocity impacts in the corner part of the dasher board ($p < .05$) so that the impacts directed to the protective shielding resulted in higher peak forces (figure 23E and F).

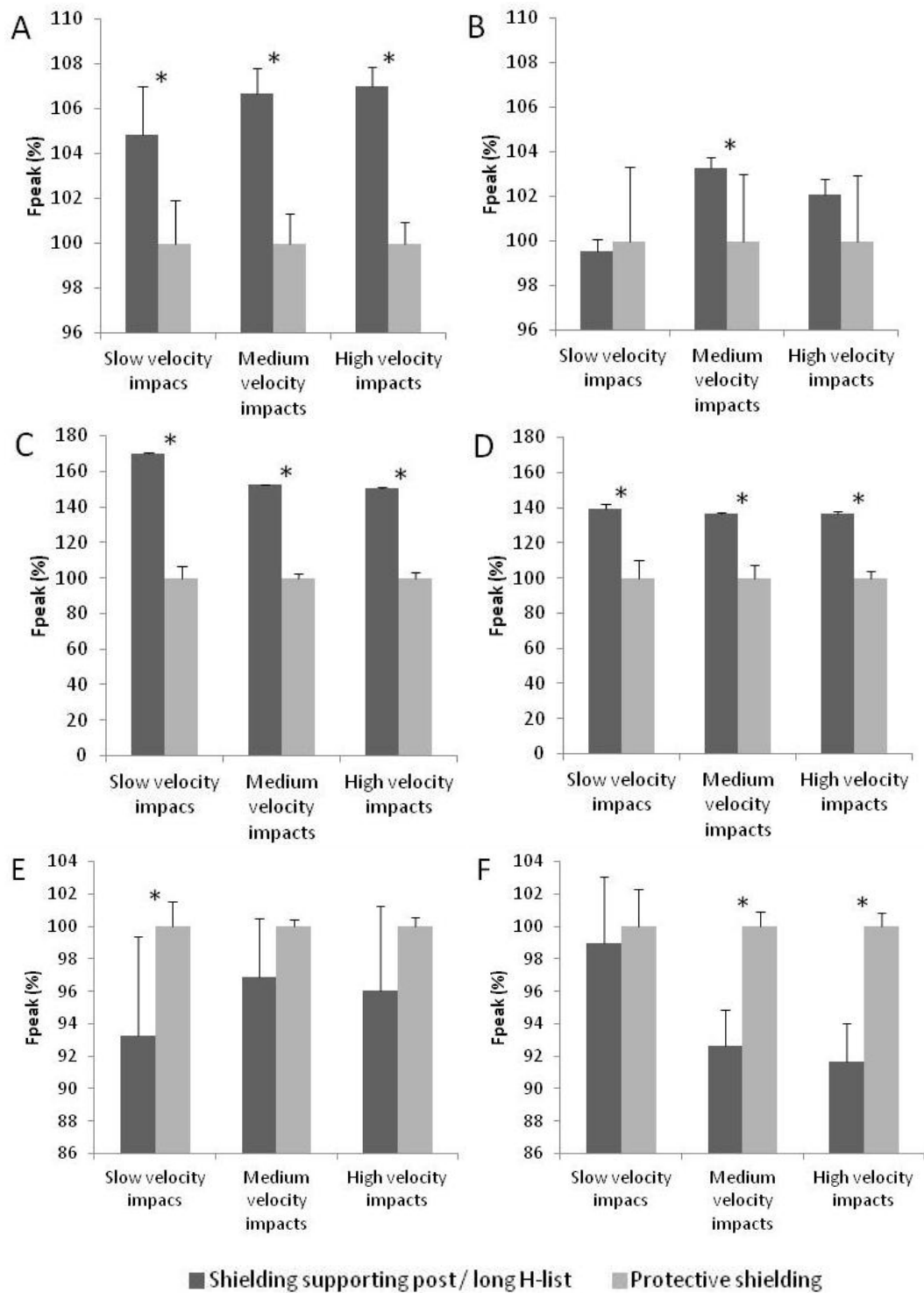


FIGURE 23. Relative peak forces of impacts directed at shielding supporting posts or long H-lists and protective shielding. 100 % reflects the value measured from the protective shielding. Figures A and B refer to the dasher board C, figures C and D to the dasher board D and figures E and F to the dasher board B. On the left side the figures represent the differences in the straight part of the dasher board and on the right side in the corner part of the dasher board.

* Statistically significant difference (p < .05).

The differences in stopping distances at the height of 30 cm in protective shielding were significant depending on the impact location. Impacts at protective shielding led up to significantly greater stopping distances in the dasher boards C and D with all impact velocities and in the straight and the corner part of the dasher board compared to impacts directed to the shielding supporting posts ($p < .05$) (figure 24A, B, C and D). Instead, in the dasher board B including long H-lists the impacts directed to the protective shielding resulted in significantly longer stopping distances with all impact velocities in the straight and the corner part of the dasher board ($p < .05$) (figure 24E and F).

In the dasher boards C and D the stiffness values were significantly higher when impacts were given at shielding supporting posts ($p < .05$) (figure 25A, B, C and D). The differences between different impact locations were significant in both dasher boards, but even more pronounced when protective shielding material was polycarbonate. In the dasher board B the protective shielding resulted to be significantly stiffer compared to long H-list with all impact velocities in the straight and the corner part of the dasher board ($p < .05$) (figure 25E and F).

In the dasher board C with tempered glass shielding the differences in the ability to absorb energy between impacts directed to the protective shielding and shielding supporting posts were significant in all the cases; shielding supporting posts led to higher energy absorption ($p < .05$) (figure 26A and B). When protective shielding material was polycarbonate, the energy absorption value of the shielding supporting posts was significantly higher in all the cases except in the corner part of the dasher board with fast velocity impacts ($p < .05$) (figure 26C and D). In that case the difference in energy absorption did not reach statistical significance although there was a strong trend to it ($p < .05$). In the dasher board B there was no statistically significant difference in the ability to absorb energy between impacts directed to the protective shielding and long H-list with fast velocity impacts in the straight part of the dasher board. In all other cases the differences in energy absorption reached significance so that long H-list was significantly better at absorbing energy ($p < .05$) (figure 26 E and F).

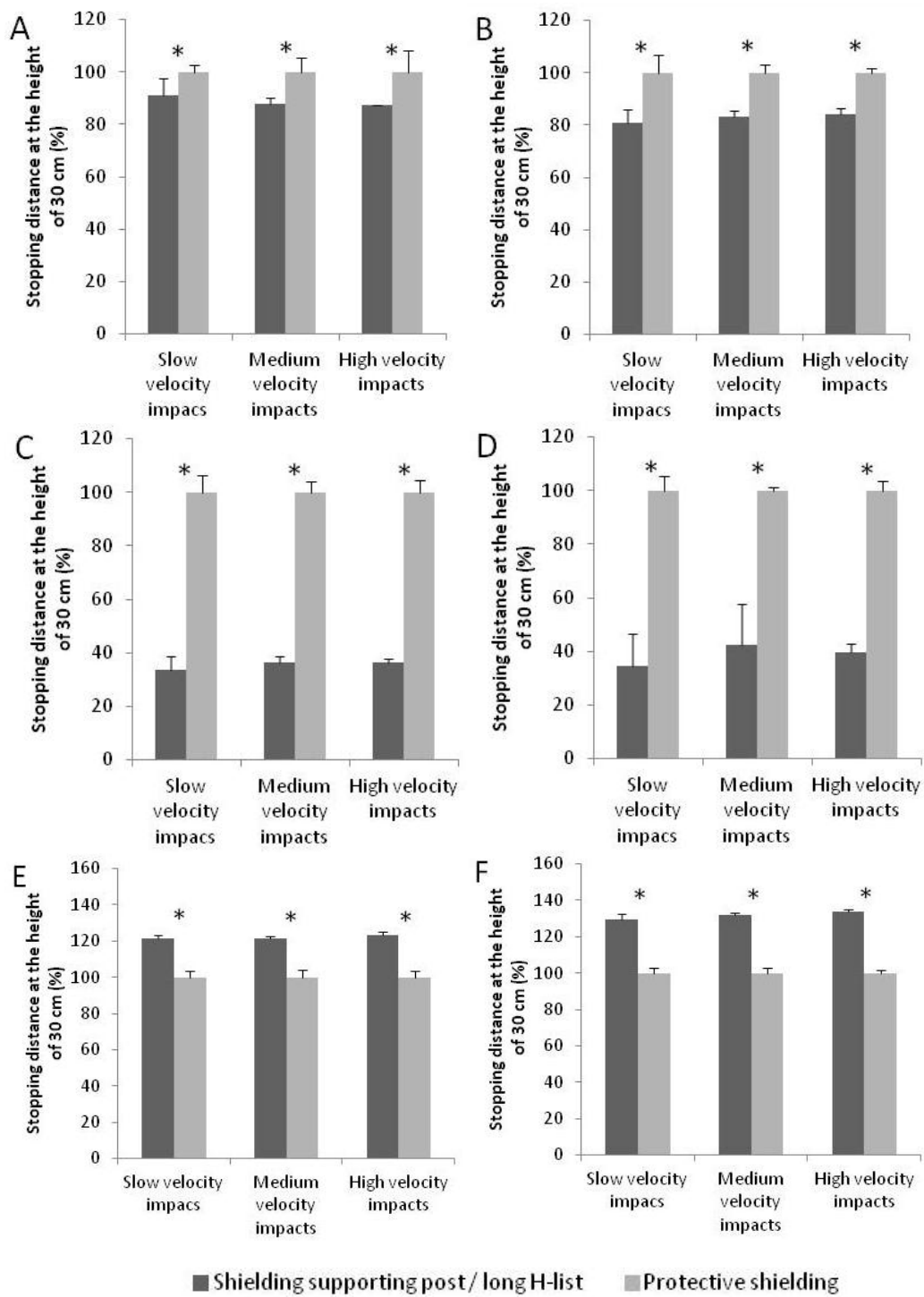


FIGURE 24. Relative stopping distances of protective shielding at the height of 30 cm of impacts directed at shielding supporting posts or long H-lists and protective shielding. 100 % reflects the value measured from the middle of the protective shielding. Figures A and B refer to dasher board C, figures C and D to dasher board D and figures E and F to dasher board B. On the left side the figures represent the differences in straight part of the dasher board and on the right side in corner part of the dasher board.

* Statistically significant difference (p < .05).

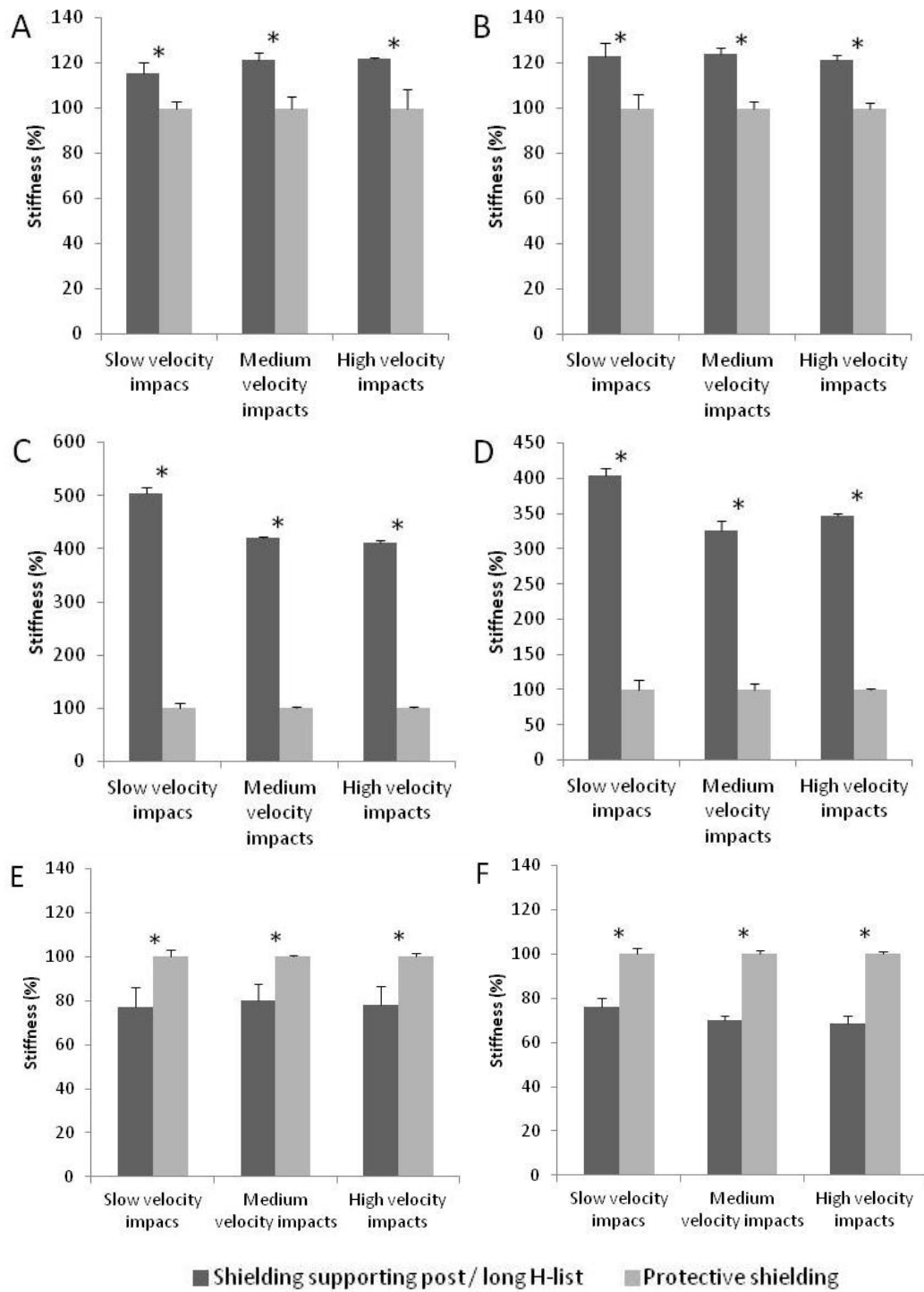


FIGURE 25. Relative stiffness values of impacts directed at shielding supporting posts or long H-lists and protective shielding. 100 % reflects the value measured from the protective shielding. Figures A and B refer to the dasher board C, figures C and D to the dasher board D and figures E and F to the dasher board B. On the left side the figures represent the differences in the straight part of the dasher board and on the right side in the corner part of the dasher board.

* Statistically significant difference (p < .05).

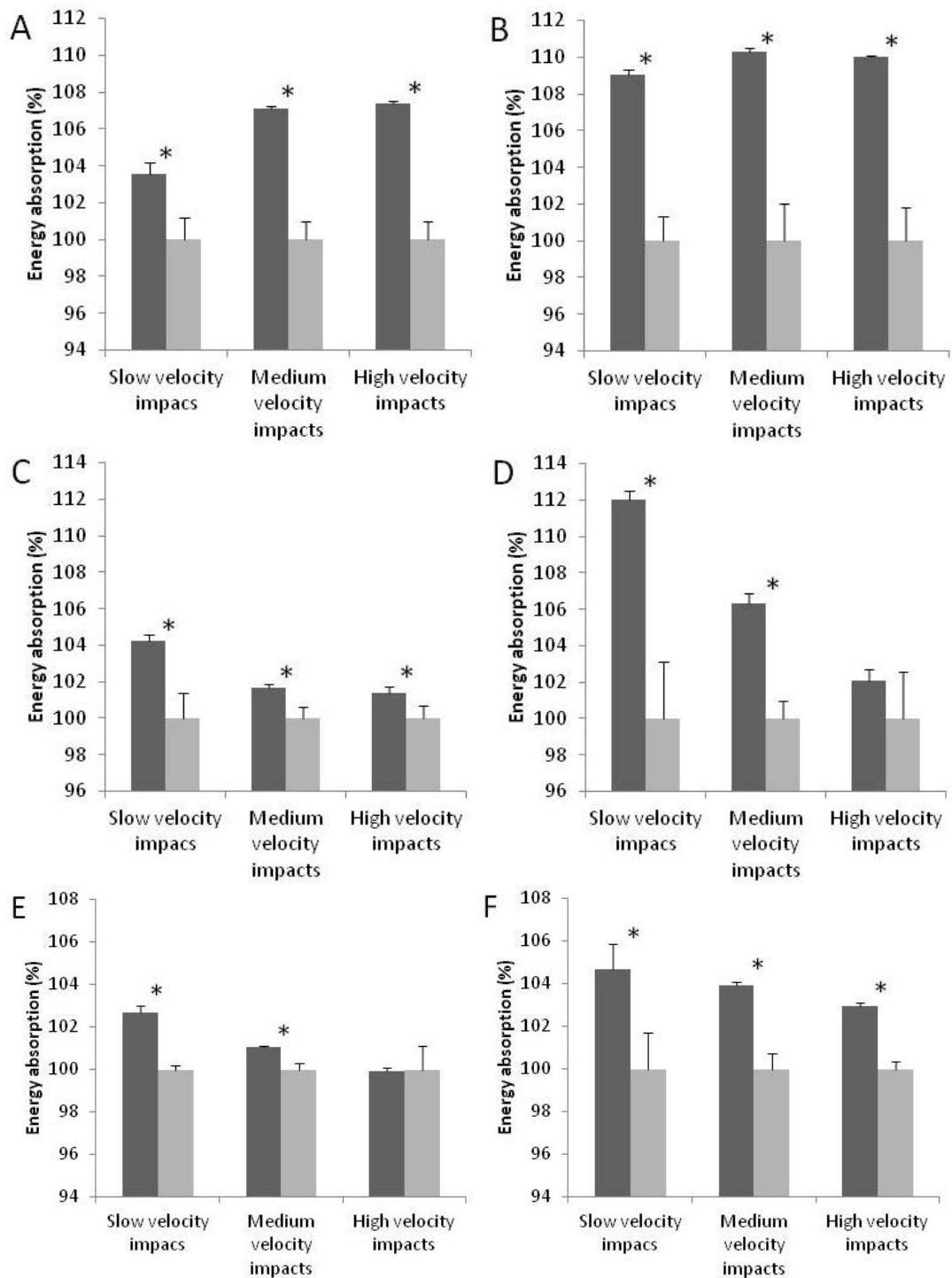


FIGURE 26. Relative energy absorption values of impacts directed at shielding supporting posts or long H-lists and protective shielding. 100 % reflects the value measured from the protective shielding. Figures A and B refer to the dasher board C, figures C and D to the dasher board D and figures E and F to the dasher board B. On the left side the figures represent the differences in the straight part of the dasher board and on the right side in the corner part of the dasher board.

* Statistically significant difference ($p < .05$).

5.3.4 Effects of frametype on element stiffness

In the straight part of the dasher board a single framed dasher board was significantly more flexible with all impact velocities compared to a dual-framed counterpart ($p < .05$) (figure 27A). In the corner part the differences in stiffness did not reach statistical significance although there was a strong trend to it (figure 27B).

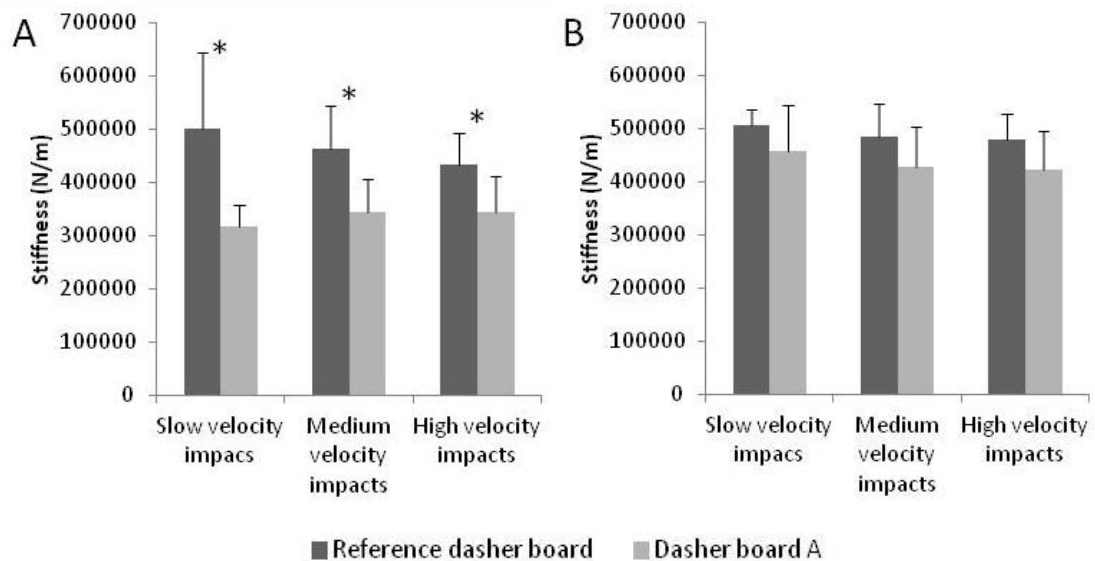


FIGURE 27. Differences in element stiffness between single- and dual-framed dasher boards in the straight (A) and the corner (B) part of the dasher board when impacting to the element.

* Statistically significant difference ($p < .05$).

5.3.5 Effects of protective shielding mass on element stiffness

Effects of the protective shielding mass on the element stiffness are shown in figure 28 in which stiffness values of two similar elements with different protective shielding materials have been compared. Tempered glass is rather heavy shielding material weighing 34 to 42 kg / m² whereas acryl weighs only 15 and 20 kg / m² (Milton et al. 2002). The differences in element stiffness were significant with all impact velocities in the straight and the corner part of the dasher board so that the element with heavier protective shielding material resulted in higher stiffness values ($p < .05$) (figure 28).

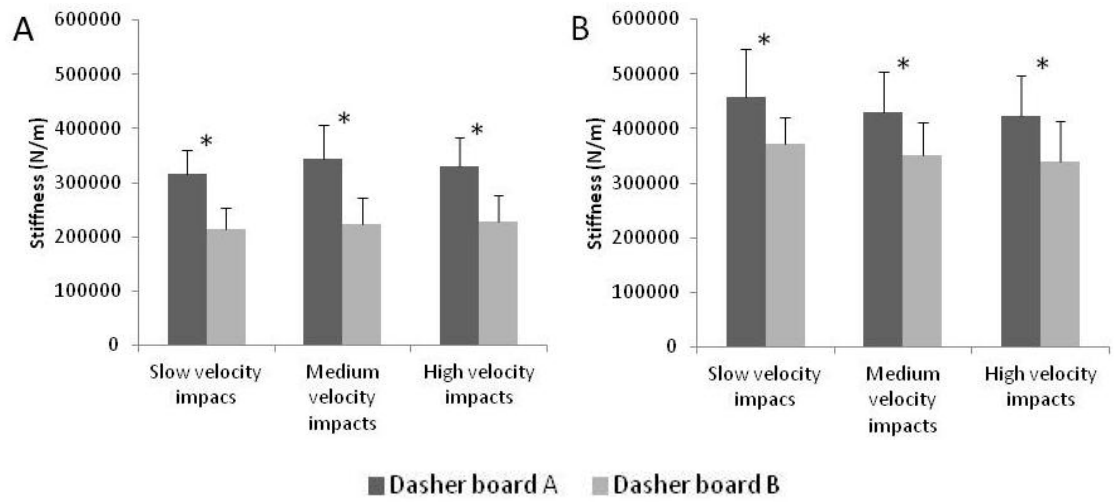


FIGURE 28. Effects of protective shielding mass on element stiffness in the straight (A) and the corner (B) part of the dasher board when impacting to the element.

* Statistically significant difference ($p < .05$).

5.4 Discussion

The main purpose of this study was to reveal how dasher board materials and structures affect impact characteristics. It was found out that dasher board materials and structures had a great role on the impact characteristics. More flexible protective shielding materials resulted in lower peak force and stiffness as well as greater stopping distance. However, the dasher boards with flexible protective shielding materials including shielding supporting posts cannot be referred consistent, and, thereby, the use of that kind of dasher boards cannot be recommended. Single-framed dasher board was noted to be more flexible than dual-framed counterpart and heavier protective shielding resulted in significantly higher element stiffness ($p < .05$).

Comparison of impact characteristics of three different dasher boards. When willing to construct more safety ice hockey arena dasher boards, one of the biggest challenge is to diminish the peak force of an impact (Marino & Potwin 2002), because it has found to be a risk factor related to concussions (Barth et al. 2001). Peak forces were the lowest in impacts given to the dasher board B, whereas, they were noteworthy higher in impacts directed to the dasher boards with tempered glass shielding. This finding was expected, because acryl is known to be more flexible protective shielding material than tempered glass (acryl has elastic modulus of 3.2 GPa whereas tempered glass has 70 GPa). Due to that the force generating time of acryl is longer, which leads to lower acceleration values and, thus, to lower peak forces (Naunheim et al. 2003). As a high peak force is a risk factor related to concussion, it is expected that the concussion risk is decreased when using more flexible protective shielding materials in ice hockey arena dasher boards.

The differences in peak forces, when impacts were directed towards protective shielding, were more subsequent to different protective shielding materials than to different element structures. This can be figured out by the fact that the differences in peak forces between impacts given to the reference dasher board and the dasher board A were not as pronounced as between impacts given to the dasher board A and the dasher board B. In the first case the only difference was the element structure, whereas, in the latter case the protective shielding materials differed.

Although the differences in peak forces were in most cases significant ($p < .05$), they were not as pronounced as in the study of Marino & Potwin (2002), in which the impact characteristics of standard and “new and soft” dasher boards were compared. They revealed that the standard dasher board produced 73 % higher peak force than the “new and soft” dasher board. (Marino & Potwin 2002.) In this study the reference dasher board produced on average 18 % and 19 % higher peak forces in the straight and the corner part of the dasher board, respectively, than the dasher board B. The findings of these two studies are parallel, but not similar. Dissimilarity could be explained by different methodology used and different dasher board materials and structures being tested; Marino & Potwin (2002) did not classify the dasher board structures in detail.

According to physics, the force exerted at an impact can be calculated by Newton’s 2nd Law, $F = ma$. The formula for calculating acceleration is $a = (v^2 - v_0^2) / 2s$ and in sports acceleration-models v is often calculated as 0, because the player is brought to a halt at the end of an impact. Thereby, the formula can be simplified to the following: $a = -v_0^2 / 2s$. When inserting the formula to determine acceleration into Newton’s 2nd Law, the Law changes to $F = mv^2 / 2s$. This equation shows us the fact that if several impacts occur all with the same initial speed (v), the bigger the stopping distance (s), the smaller is the resulting force. This is an important fact when creating more safety dasher boards. (Barth et al. 2001.)

At the height of 30 cm and 60 cm in protective shielding the differences in stopping distances were significant ($p < .05$). The dasher board B had even more than 100 % longer stopping distances than the reference dasher board. The dasher board A, instead, had 15 – 20 % longer stopping distances when compared to the reference dasher board. The difference varied depending on the impact velocity and the impact location.

Relative differences in stopping distances of protective shielding between the reference dasher board and the dasher board A were greater when impact velocities were high. Instead, the differences were more pronounced between the reference dasher board and the dasher board B with slow velocity impacts. The only difference in the first case was the element structure, thus, showing that the element structure does not affect impact characteristics with slow velocity impacts; for that higher impact velocities are needed.

The structural and material differences are more pronounced between the reference dasher board and the dasher board B; the element structures as well as protective shielding materials differ. Thereby, the differences in stopping distance appear already with slow velocity impacts.

In physics, stiffness is the determinant of the amount of movement of the boards relative to the force of the collision. Thus, the dasher board with high stiffness value can be categorized with greater concussion risk at an impact (Marino & Potwin 1998). Because both, peak force and stopping distance, affect stiffness, the findings were parallel to those findings. The dasher board B was the most compliant dasher board, whereas, the reference dasher board was the stiffest one. Thereby, based on the stiffness values the reference dasher board can be classified as the most dangerous dasher board of the tested ones and the dasher board B leads to the lowest concussion risk. The relative differences seems to be great, but Marino & Potwin (2002) made similar findings in their study discovering that the standard dasher board was 136 % stiffer compared to the “new and soft” dasher board.

Energy absorption reflects how much energy is absorbed at an impact and based on the literature high energy absorption value would be desirable, because it reflects smaller amount of energy returned to the player (Marino & Potwin 1998). As the mass of the pendulum was unchanged and impact velocity controlled, it was expected that the dasher board with the lowest peak force and the longest stopping distance, in this case dasher board B, would have had the highest ability to absorb energy. However, the energy absorption did not act exactly like that.

Particular behavior of energy absorption could, at least partly, be explained by elastic properties of acrylic shielding. Based on the obtained information from manufacturer the Young's Modulus of acryl is much smaller being approximately 3.2 GPa compared to the corresponding value of tempered glass, which is around 70 GPa. Due to the low Young's Modulus the acrylic protective shielding might “bounce back” after an impact leading to high post-impact kinetic energy value and, thereby, to low energy absorption. Therefore, the protective shielding leading to a low peak force due to a long force generating time and a great stopping distance does not automatically head to good energy

transmission and damping capability. In addition, as a material acrylic is much lighter than tempered glass, whereupon, the energy absorption do not reach such high values.

As it was expected, there were differences in impact characteristics between the corner and the straight part of the dasher board. Peak forces and stiffness values were remarkably lower and stopping distances of an element longer when impacting to the straight part of the dasher board compared to the values recorded from its corner part. These findings prove that the element structure is more flexible from the straight part of the dasher board. However, the stiffer element structure in the corner part of the dasher board did not affect stopping distances of the protective shielding at the height of 30 cm and 60 cm. This finding was expected, because the inter shielding systems used (clips and long H-lists) allow each piece of protective shielding to move independently upon impact. If the protective sheets were attached strictly together, the stiffness of an element would have also affected the stopping distances of the protective shielding.

When discussing about the differences in impact characteristics between different dasher boards it must be kept in mind that the element width differed; the reference dasher board had longer elements than the dasher boards A and B. If the reference dasher board elements had been the same width as the elements of the dasher boards A and B, the differences in impact characteristics might have been even greater, because shorter element is expected to be stiffer. Thereby, differences in the impact characteristics between the reference dasher board and other dasher boards might be slightly underestimated in this study. However, the measured dasher boards were commercially available ones and, thus, the width differences were intentional.

Impact characteristics between the protective shielding and the shielding supporting posts or long H-lists. The aim was to find out, how consistent the different dasher board structures are. Therefore, there was an interest to know how much impact characteristics differ between impacts given to the protective shielding and the shielding supporting posts or long H-lists. In the dasher boards C and D including shielding supporting posts the peak forces, stiffness values and ability to absorb energy were remarkably higher and stopping distances shorter when impacting to the shielding supporting posts compared to impacts directed to the protective shielding. Instead, in the dasher board B the

impacts directed to the long H-lists resulted in lower peak forces and stiffness values as well as shorter stopping distances and higher ability to absorb energy than impacts given at protective shielding.

In dasher board D with polycarbonate protective shielding the shielding supporting posts were approximately 342 % and 260 % stiffer in the straight and the corner part of the dasher board, respectively, compared to the protective shielding. When the protective shielding was made of tempered glass, the corresponding difference was on average 21 % and 23 % in the straight and the corner part of the dasher board, respectively. In the dasher board B with acrylic protective shielding the long H-lists resulted approximately 21 % and 29 % lower stiffness values in the straight and the corner part of the dasher board, respectively, than the protective shielding. Thereby, the differences were most pronounced in the dasher board D including protective shielding made of polycarbonate sheets. Even if, the differences reached significance in most cases also in the dasher boards B and C, they can be considered much more consistent than the dasher board D.

In the dasher board D the body checks may not be dangerous when they are directed to a protective shielding, but when a player hits with shielding supporting post, it could be compared to the hitting with an almost immovable object, which increases the risk of injury. For example, the stopping distance of polycarbonate protective shielding at the height of 30 cm in protective shielding with fast velocity impacts was on average over 11 cm. If a player hits with protective shielding and then suddenly collides with less flexible shielding supporting post, it might be critical. Thereby, the principal question is, whether it is safe to have very flexible protective shielding material, such as polycarbonate, which requires shielding supporting posts to keep the structure in shape.

Single- vs. dual-framed dasher board. As it was expected, the single-framed dasher board resulted to be more flexible than the dual-framed counterpart, but the difference in stiffness reached significance only in the straight part of the dasher board ($p < .05$). Greater differences in the stiffness at the straight part of the dasher board compared to the corner part of the dasher board suggests that the structural properties of single- and dual-framed dasher boards are more equal in the corner part. The differences in stiffness values were more pronounced with slow velocity impacts, which uncovers, that slow

velocity impacts are not strong enough to cause significant deformations in a dual-framed dasher board, whereas, in a single-framed counterpart deformations take place already with slow velocity impacts.

Effects of protective shielding mass on element stiffness. Protective shielding mass had an influence in element stiffness. Heavier protective shielding material resulted in significantly greater element stiffness ($p < .05$). Lately there have been arguments in favor of and against whether protective shielding should be higher at the end zones of the rink to ensure spectators' safety. As higher protective shielding increases its mass, in the light of these findings, the element structure becomes stiffer and, thereby, players' risk for injury is higher. Based on these facts, the use of higher protective shielding is not recommended, especially since, the compulsory net takes care of the safety aspects.

In the future. Although this study was rather comprehensive and increased understanding about ice hockey arena dasher boards and the effects of materials and structures on impact characteristics, there are still many questions under debate. In the future the investigation related to the players' safety and dasher boards must be continued with an aim to be able to construct more safety ice hockey arena dasher boards.

One of the questions still under debate is which element height is the most beneficial one, when aiming to reduce the amount of concussions and other injuries. In the rules of International Ice Hockey Federation (IIHF) it is determined that the element must be 1.170 - 1.220 meters in height above the level of the ice surface (International ice hockey federation, 2010b). In the regulations of National Hockey League (NHL), instead, it has been defined that the element shall extend no less than 1.016 meters and not more than 1.219 meters in height above the level of the ice surface (National Hockey League, 2011). In this study the simulation of element height on impact characteristics was carried out. Because there were no elements with NHL element height, the impact location was moved 14 cm higher in protective shielding to simulate the impact height of shoulder with 14 cm lower element. The differences in peak forces were rather small, but the trend was clear; the impacts given 14 cm higher led up to about 5 % lower peak forces. However, if the element height was lower, the element structure would be stiffer. Thereby, the results overestimate the real difference and they cannot be considered reli-

able. In the future the effects of an element height on impact characteristics should be investigated more in detail and with appropriate element heights.

To the author's knowledge, there is only one article published (Marino & Potwin 2002) comparing impact characteristics of different ice hockey arena dasher boards. The topic is relevant and of current interest and, thereby, in the future the investigation of more safety dasher boards should be of concern. It could be beneficial to construct a standardized pendulum system with known pendulum weight and material as well as known lever arm and dropping heights. It would enable the comparison of the results between studies done by different bodies of research and, thereby, could expand our understanding of the effects of dasher board structures and materials on impact characteristics.

Conclusion. With this study it has been shown that modification of the materials and structures of the dasher boards give an opportunity to affect impact characteristics and, thereby, the concussion risk. In the light of the results and the epidemiology of concussions it seems that the most safety dasher board would be single-framed with light and flexible protective shielding material and it would not include shielding supporting posts. However, constructing safety and, at the same time, competitive dasher boards is not a simple process, because light protective shielding materials have a huge disadvantage; they do not provide clear view for spectators and media at least if watching from an angle (Milton et al. 2002). Nowadays "seamless acrylic shielding", which reflect light towards spectators 8 – 33 % less than the older acrylic materials, has already been innovated (Sports Systems Unlimited Corp 2011), but unfortunately, the view is not yet clear. Therefore, the further development of dasher board materials and structures as well as the investigation of their effects on impact characteristics must be continued.

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