

Relationship between floor type and risk of ACL injury in team handball

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The purpose of this study was to compare the ACL injury rate between two different floor types – wooden floors (parquet, generally having lower friction) and artificial floors (generally having higher friction). ACL injuries have been recorded prospectively from the three top divisions for men and women in Norwegian team handball during seven seasons (1989–2000). A total of 174 ACL injuries have been recorded, and of these 53 occurred in regular league games. The floor types for all regular games from the same seasons have been determined retrospectively based on match schedules. The matches were divided into two groups: those played on wooden floors and those played on artificial floors. A total of nine injuries occurred among men (incidence:

0.24 ± 0.09 injuries per 1000 player hours) and 44 among women (0.77 ± 0.04 injuries 1000 h^{-1} ; OR vs. men: 3.21 (1.56–6.58); $P = 0.001$). Among men, four injuries occurred on wooden floors (0.32 ± 0.13 injuries 1000 h^{-1}) and five injuries occurred on artificial floors (0.20 ± 0.12 injuries 1000 h^{-1} ; OR vs. wooden floors: 0.63 (0.17–2.37); ns). Among women, eight injuries occurred on wooden floors (0.41 ± 0.09 injuries 1000 h^{-1} ; OR vs. men: 1.29 (0.39–4.28); ns) and 36 on artificial floors (0.96 ± 0.04 injuries 1000 h^{-1} ; OR vs. wooden floors: 2.35 (1.09–5.07); $P = 0.03$; OR vs. men: 4.77 (1.87–12.18); $P = 0.001$). These results indicate that the risk of ACL injury for women is higher on artificial floors than on wooden floors.

The incidence of ACL injuries seems to have increased over the last 10–15 years. Studies from US college sports (basketball, soccer and gymnastics) and European team handball have shown that female athletes are at increased risk for ACL injuries compared with men (Arendt & Dick, 1995; Hutchinson & Ireland, 1995; Myklebust et al., 1998; Arendt et al., 1999). The rate of ACL injury is 3–5 times higher among women in indoor ball games than among men.

The reasons for this gender difference are unknown. A number of risk factors have been suggested, both intrinsic, e.g., anatomic, strength, coordination, hormonal, previous injury, level of skill and conditioning, and extrinsic, e.g., shoe and surface type. Studies have suggested that there may be a relationship between the shoe–surface interface and injury risk (Strand et al., 1990; Myklebust et al., 1997; Orchard et al., 1999; Orchard & Seward, 2002). We have analyzed videotapes of 20 ACL injuries in team handball, showing that the injuries usually occur during a non-contact plant and cut movement or when landing from a jump shot (Olsen et al., 2003, unpublished data). The injury mechanism in all cases is a forceful valgus-external or -internal rotation with the knee close to extension, and it appears that the

ACL tear occurs at the time when the foot is planted and firmly fixed to the floor.

Strand et al. (1990) found in a retrospective study from team handball that playing on wooden floors (parquet) resulted in a significantly lower ACL injury incidence than on artificial floors. Two prospective studies, one from team handball and one from soccer, did not find such a relationship (Engström et al., 1991; Myklebust et al., 1998). A prospective study from the Australian Football League shows that soft ground, which is assumed to lower shoe–surface traction, lowered the risk of non-contact ACL injuries (Orchard et al., 1999). Another prospective study showed that shoes with a greater number of cleats and higher torsional resistance were associated with an increased number of ACL injuries in American football (Lambson et al., 1996). Taken together, these studies suggest that the shoe–surface interface could be an extrinsic risk factor for ACL injuries in team handball. A hypothesis is that high friction between the shoe and surface increases the injury risk, since the foot seems to be fixed to the floor at the time of injury.

The aim of this study was to compare the ACL injury rate between two different floor types – wooden floors (parquet, generally having lower

friction) and artificial floors (generally having higher friction).

Material and methods

The present study was based on injury data collected as part of three previous studies (Myklebust et al., 1997, 1998, 2003). In these studies, ACL injuries were recorded prospectively in Norwegian team handball during seven seasons: from the top three divisions for men and women (212 teams, 3392 players each season) during the 1989–91 seasons, from the elite divisions for men and women (24 teams, 384 players each season) during the 1993–96 seasons and from the top three divisions for women (60 teams, 950 players each season) during the 1998–2000 seasons. The players on these teams were either amateurs or semi-professionals. Information about injured players was gathered from team coaches, physiotherapists, physicians and the insurance company. An ACL injury was registered if it occurred during organized handball training or games. All the injured players consented to participate in an interview within approximately 10 weeks (range: 1 week to eight months) after the injury, either in person or by telephone. The interviews of the injured players were conducted by physiotherapists based on a standardized questionnaire (Table 1). Data on injury mechanisms and the floor type on which the injuries occurred were collected. The diagnosis of an ACL injury was subsequently verified from hospital medical records.

A total of 174 ACL injuries were recorded during the seven seasons studied. Of these, 53 injuries occurred in regular league matches and these were included in this present study. Injuries occurring in other matches (tournaments, national or international cup games, $n = 81$) or training ($n = 40$) had to be excluded, since exposure data on floor types were not available for these games and practices. However, information on all regular league matches from the same seven seasons was available from the match records of the Norwegian Handball Federation.

Through these records the venue for each game could be identified, and information on the floor type at each venue was collected based on registries at the Ministry of Cultural Affairs and the Norwegian Building Research Institute (NBI). A total of 6746 regular league matches were played during the

seven seasons studied. Information about the floor type was available for all but 22 of these matches and these 22 matches were excluded from the analysis. The matches were played in 261 different venues, 91 of these with wooden and 170 with artificial flooring. The matches were played with equipment and rules in accordance with the regulations of the International Handball Federation.

For the purpose of the analysis, the matches were grouped in two: those played on wooden floors and those played on artificial floors. The grouping was chosen based on friction tests on different floor types conducted by NBI in the period from 1990 to 2000 (Hegermann, 1995). NBI used a DIN test to measure the friction (NBI, 1996), where a vertical load of 200 N is applied to a test-foot with a leather surface pressed down on the floor with a constant rate of rotation. The friction coefficient (μ) was calculated by the formula $\mu = 0.3M/F$, where M is the measured torque in Ncm, F is the normal force in N and 0.3 is a constant estimated on the basis of the model of the test-foot. The wooden floors that were tested ($n = 13$) had a friction coefficient of 0.45 ± 0.06 (SD) (range: 0.36–0.53) compared with 0.54 ± 0.05 (0.46–0.73) for artificial floors ($n = 60$) ($P < 0.001$, unpaired t -test) (NBI 2000, personal communication). NBI had tested seven of the 91 venues (8%) with wooden floors that were used for the matches included in the present study (friction coefficient: 0.46 ± 0.07 (0.37–0.53)) and 22 of the 170 venues (13%) with artificial floors (0.57 ± 0.05 (0.53–0.73)) ($P < 0.001$, unpaired t -test).

Competition exposure

Competition exposure on each floor type was calculated as the number of matches multiplied by the duration of each match (2×30 min) multiplied by 14 players (two teams with seven players on each team), i.e., a total of 14 player hours per match. Injury incidence was calculated as the number of ACL injuries reported per 1000 player hours for each floor type and gender. Injury incidence is presented as the mean \pm SEM.

Statistical methods

A z -test based on log odds ratio (OR) was used to compare the OR between floor types (wooden vs. artificial) and genders (men vs. women). Fisher's exact test was used to calculate the P -value in cases where the minimum number of cases was five or less. The test of interaction between floor types and genders was conducted by comparing OR between floor types for men and women by a z -test. OR are presented with 95% confidence interval. An α level of 0.05 was considered as statistically significant.

Results

During the seven seasons, a total of 6 724 regular league matches were played for a total of 94 136 player hours (57 022 h for women and 37 114 h for men) (Table 2). During this period, there were 53 ACL injuries in regular league matches, nine among men (0.24 ± 0.09 injuries per 1000 player hours) and 44 among women (0.77 ± 0.04 injuries 1000 h⁻¹; OR vs. men: 3.21 (1.56–6.58); $P = 0.001$).

Table 1. Data collected in the standardized questionnaire

1.	Age
2.	Gender
3.	Team name
4.	Division
5.	Date of injury
6.	Name of the venue where the injury occurred
7.	Whether the injury occurred during practice or game
8.	Type of match (regular league, tournament, cup, European cup, national team)
9.	Which type of floor the injury occurred on (wooden, parquet)
10.	How the injury occurred (playing phase, activity, handling the ball)
11.	Field position when the injury occurred (back -, wing -, line player, goalkeeper)
12.	If there was any contact with an opponent when the injury occurred
13.	If the player had been operated or an operation was planned for; when and where
14.	Permission to obtain their hospital records

Relationship between floor type and risk of ACL

Table 2. Number of ACL injuries, exposure and injury incidence on the two floor types during seven seasons: from the top three divisions for men and women (212 teams, 3392 players each season) during the 1989–91 seasons (Myklebust et al., 1997), from the elite divisions for men and women (24 teams, 384 players each season) during the 1993–96 seasons (Myklebust et al., 1998) and from the top three divisions for women (60 teams, 950 players each season) during the 1998–2000 seasons (Myklebust et al., 2003). Incidence is reported as the number of injuries per 1 000 player hours

	Wooden floors						Artificial floors					
	ACL injuries		Exposure (h)		Incidence		ACL injuries		Exposure (h)		Incidence	
	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men
1989–91	6	4	10 752	11 116	0.56±0.11	0.36±0.13	16	4	21 252	20 468	0.75±0.07	0.20±0.13
1993–96	1	–	1680	1386	0.60±0.27	–	4	1	3850	4144	1.04±0.13	0.24±0.27
1998–2000	1	–	7042	–	0.14±0.27	–	16	–	12 446	–	1.29±0.07	–
Total	8	4	19 474	12 502	0.41±0.09	0.32±0.13	36	5	37 548	24 612	0.96±0.04	0.20±0.12

Player characteristics

The age of the injured players was 22 ± 4 (SD) years (17–33) for women and 26 ± 3 years (21–29) for men. Forty-four of the 53 ACL injuries were sustained by back and wing players. Forty-one of the injuries occurred in the attacking phase (37 handled the ball) and 12 in the defensive phase (three handled the ball). Five injuries were reported as a collision injury, but reliable information on whether these injuries resulted from a direct blow to the injured knee or leg was not available. Nineteen injuries occurred in a plant and cut movement and 16 occurred when landing from a jump shot. Thirty-seven injuries were non-contact injuries.

Effect of floor types

A total of 4440 matches (62 160 h) were played on artificial floors and 2 284 matches (31 976 h) on wooden floors (Table 2). Of the 53 injuries, 12 occurred on wooden floors (0.38 ± 0.08 injuries 1000 h^{-1}) and 41 on artificial floors (0.66 ± 0.04 injuries 1000 h^{-1} ; OR vs. wooden floors: 1.76 (0.93–3.36); $P = 0.08$). Among men, four injuries occurred during 893 matches on wooden floors and five during 1758 matches on artificial floors (OR vs. wooden floors: 0.63 (0.17–2.37); ns) (Table 2). Among men in the elite division, no injuries occurred during 165 matches (2310 h) on wooden floors and three during 494 matches (6 916 h) on artificial floors (0.43 ± 0.15 injuries 1000 h^{-1}). Among women, eight injuries occurred during 1 391 matches on wooden floors (OR vs. men: 1.29 (0.39–4.28); ns) and 36 during 2 682 matches on artificial floors (OR vs. wooden floors: 2.35 (1.09–5.07); $P = 0.03$; OR vs. men: 4.77 (1.87–12.18); $P = 0.001$; $P = 0.09$, test of interaction) (Table 2). Among women in the elite division, two injuries occurred during 289 matches (4046 h) on

wooden floors (0.49 ± 0.19 injuries 1000 h^{-1}) and 14 during 633 matches (8 862 h) on artificial floors (1.58 ± 0.07 injuries 1000 h^{-1} ; OR vs. wooden floors: 3.25 (0.73–14.38); ns; OR vs. men: 3.70 (1.06–12.95); $P = 0.04$, Fisher exact test).

Discussion

The main observation of this study was that the risk of ACL injury for women appears to be higher on artificial floors than on wooden floors. Consequently, the ACL injury rate was higher for women than for men on artificial floors, while there was no gender difference on wooden floors.

Methodological considerations

When interpreting the results from the present study, there are some limitations that must be considered. Firstly, the low number of injuries means that the results should be interpreted with caution. We have injury data on a total of 174 ACL injuries, but since reliable floor type exposure data was available for regular league matches only, we had to eliminate two-thirds of the injuries ($n = 121$) from the analysis. Therefore, it is not possible to detect significant differences when breaking down into subgroups on, e.g., gender or playing level, even when the odds ratio appears to be as high as 3–4 in some cases. In particular, since there are few injuries among men, the results on a possible gender difference between wooden vs. artificial floors must be interpreted with caution. This hypothesis must be tested in future studies with a sufficient number of cases. With more cases and exact data on the friction characteristics of each venue, it would be possible to examine the relationship between floor friction and injury risk in

a regression model, not simply comparing artificial floors with wooden floors.

Secondly, although the purpose of this study was to compare injury risk between floors with high friction vs. floors with low friction, we had to use a model comparing artificial floors with wooden floors. This approach can be questioned, as these two groups of sports floors are not homogeneous and the shoe–surface friction within each group differs considerably. In the artificial floor group, some of the older floor-covering materials have very high friction, whereas newer artificial floors with polyurethane coverings have a low friction coefficient in the same range as wooden floors. Also, freshly lacquered/painted wooden floors can have very high friction. Nevertheless, the trend among the floor types tested was for the artificial floors to have higher friction coefficients (range: 0.46–0.76) and wooden floors lower friction coefficients (range: 0.36–0.53). Moreover, the large range within each category would tend to cause a type II error, i.e. mask the true relationship between friction and injury risk. Other potential confounding factors include the age of the floor, the cleaning and maintenance routines (waxing, solvent use), the use of stick 'em (to improve their grip, handball players put glue on their hands, which easily transfers to the ball and floor) and shoe types (see below).

Thirdly, the fact that friction measurements were only available for a sample of the floors, as well as the method used to determine friction, may be questioned. The NBI test method measures the friction coefficient at a constant rate of rotation with a vertical load of 200 N. However, the method does not necessarily take into account the elastic properties of artificial floors. The NBI test employs a circular rotating disk of three segments with a leather surface, which means that after the initial deformation caused by vertical compression, no further deformation needs to occur. However, in real life, e.g., when a sports shoe slides on an elastic floor, a floor “wave” is created in front of the shoe, which has to be overcome. This friction component, caused by elastic deformation, is not detected with the NBI test, and does not occur on hardwood floors. Also, the test measures sliding friction, not starting friction. Consequently, the friction difference between wooden and artificial floors may be considerably greater than that detected with the NBI test.

Moreover, the shoe type worn is also an important factor. We have, with the NBI, performed friction test on 29 courts, with eight different floor types and different shoes (Hegermann, 1995). The test used was designed to simulate the friction that would occur in a cutting move. The data indicate that the shoe–floor friction varies among the different types of shoes and different types of floors, e.g., one shoe had a value of

0.78 and another shoe 1.41 on the same wooden floor. Nevertheless, except for newly lacquered parquet, which was difficult to test, the friction was consistently higher on artificial floors than wooden floors, regardless of shoe type. As we do not have data on the shoe types the players used in the present study, we were not able to study the relationship between shoe–surface traction and injury risk directly. This is probably not even possible, given the large number of manufacturers and shoe types available.

Ideally, we would have wanted to include non-contact injuries only in the present study, because a direct blow to the knee or leg could probably cause an ACL injury independent of the shoe–surface interface. Even so, we have included five injuries where the players reported contact with an opponent, because this contact was reported as a push or holding to the upper part of the body, and not as a direct blow to the knee or leg. We also know, based on video analysis of 20 ACL injuries, that although the injured players reported 38% of the cases as contact injuries, there was no contact with the lower extremities in all but one case (Olsen et al., 2003, unpublished data). Thus, it is not possible to exclude contact injuries reliably based on questionnaire information alone.

The injury data were collected using a prospective study design in close contact with the team coaches and medical staff throughout the study periods, and they were requested to report ACL injuries as soon as they occurred. Also, all the insurance claims were examined for additional ACL injuries. Even so, there is always a possibility that an injury may have been overlooked. However, an ACL injury usually causes pain, swelling and disability, and it is unlikely that a player may have developed an injury without the need for medical follow-up. All the ACL injuries were verified arthroscopically and in most of the cases, reconstructive surgery was performed. It is therefore highly unlikely that there may have been “false-positive” ACL injuries or that injuries were overlooked during the study periods. Also, if injuries were lost, it does not seem likely that there would be a bias for either floor type.

With respect to exposure registration, it was possible for us to record the exact exposure for all regular league matches, as the information was obtained from the match records of the Norwegian Handball Federation. Through these records, the venue for each game was identified, and information on the floor type at each venue was collected based on registries at the Ministry of Cultural Affairs and the NBI. The number of players and hours was also the same for all matches. Consequently, we have exact data on the different floor types where the matches were played, and the reliability of the injury,

exposure and floor type registration can be assumed to be excellent.

Risk factors

From a prevention point of view, the most promising extrinsic risk factor for ACL injuries may be the shoe–surface interface characteristics (Strand et al., 1990; Myklebust et al., 1997). It has been hypothesized for many years that increasing the friction between the athlete's shoe and the floor would cause an increase in the rate of ACL injuries. Several studies have indicated that there may be a relationship between injury risk and surface conditions (Strand et al., 1990; Myklebust et al., 1997; Orchard et al., 1999; Orchard & Seward, 2002).

Strand et al. (1990) conducted a retrospective study on 144 ACL injuries in team handball, all verified by arthroscopy or surgery at three hospitals in Norway. They found that the incidence was 0.82 injuries per 1000 hours in female athletes playing at a high division level, mainly on artificial surfaces. The risk in other groups (lower level, younger and/or male athletes), and when playing on wooden floors, was considerably lower. They therefore concluded that playing on wooden floors resulted in a lower injury incidence than on artificial floors. The study also indicated that there could be differences between the different types of artificial floors as well. Two prospective studies, one from team handball and one from soccer, could not find a relationship between the injury incidence and surface (Engström et al., 1991; Myklebust et al., 1998), but these studies probably included very few injuries to detect any difference.

A prospective study from the Australian Football League (AFL) suggested that the ground condition was a factor for the incidence of ACL injuries (Orchard et al., 1999). They found that low water evaporation and high rainfall significantly lowered the risk of non-contact ACL injuries in AFL footballers. The likely mechanism was a softening of the ground, which lowers shoe-surface traction.

Although the apparent male–female difference in injury rates on different floor types should be interpreted with caution, experimental data also seem to suggest that males and females may respond differently to high-friction floors. Hewett et al. (1999) found that neuromuscular training, using strength and technique exercises, resulted in fewer major knee injuries for female high school athletes in basketball and soccer. In a previous study, they also found that this training program reduces the forces when landing or when running with change of direction, and also increases the strength in the hamstrings vs. the quadriceps (Hewett et al., 1996). Rozzi et al. (1999) found that healthy female college athletes

Relationship between floor type and risk of ACL

had, compared with healthy male college athletes, greater knee laxity, less joint proprioception, less balance standing on one leg and greater muscle activity (EMG) in lateral hamstring muscle subsequent to landing from a jump. Huston & Wojtys (1996) found among both female elite athletes and non-athletes a greater knee laxity, less muscle strength and less endurance compared to male elite athletes. So a high shoe–surface traction combined with the intrinsic risk factors mentioned could potentially put female athletes at higher risk. Further research on both intrinsic and extrinsic risk factors for ACL injuries, especially among women, is needed.

Practical implications

To prevent non-contact ACL injuries in team handball and other ball games the data available seem to indicate that floor types, either wooden or artificial, with as low shoe-surface traction as possible, yet still providing sufficient friction to allow optimal performance, should be sought. Thus, we recommend that:

- (1) Information about the friction characteristics of each venue be made available to the athletes based on standardized tests, which take into account the limitations discussed earlier. Ideally, such tests should be developed to take into account differences in shoe characteristics.
- (2) Regulations that limit the maximum friction allowed for new sports floors be established.
- (3) Shoe manufacturers be encouraged to take safety issues, not only performance characteristics, into consideration when developing new shoe types.
- (4) Players be encouraged to have at least two different types of shoes to match the floors on which they will compete. Today, players usually use the same shoes when playing on wooden floors as on artificial floors.
- (5) Cleaning and maintenance routines be developed to maintain conditions as constant as possible.
- (6) Limitations on the use of hand glue should be considered.

Perspectives

It is possible that measures to reduce shoe–surface traction, such as cleaning and maintenance routines, limitations on use of hand glue, use of newer artificial floor types with acceptable friction and use of different types of shoes with friction characteristics matching the floor type they are used on, would all reduce the risk of ACL injuries in team handball. Further studies with more injuries and more accurate measurements of friction are needed.

Conclusions

The results indicate that the risk of ACL injury for women is higher on artificial floors than on wooden floors. It is assumed that the increased risk results from the high friction on some artificial floors.

Key words: ACL injury; surface; risk factors; European team handball.

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