Variation of cross-country ski characteristics

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INTRODUCTION

In cross-country skiing the technical equipment of an athlete constitutes a substantial part of the end performance. A major effect of ski span characteristics on gliding results was reported as far back as the 1980s (Ekström, 1980). Each season, world class athletes spend a large amount of time with their ski technicians to find the best possible skis suited for their individual technique, competition form and track characteristics. Equipment regulations from the International Ski Federation (FIS) and the International Biathlon Union (IBU) clearly define the demands and restrictions for racing skis. There are no limits for the type of construction, as well as no restrictions with regard to the rigidity in all grades of flex as long as the weight of a pair exceeds 750 grams without bindings (FIS, 2010; IBU, 2010a).

Cross-country courses are described as a combination of uphill climbs of various gradients, undulating flat terrain and technical downhills (FIS, 2008a; FIS, 2008b). The competition rules from the IBU are less descriptive, although their specification of the ratio between total climb to competition distance of 2.7 to 4.5% is in accordance with FIS rules (IBU, 2010b). A major difference between Biathlon (BI), Nordic Combined (NC) and Cross Country (CC) is both competition distances and course lengths. Almost all courses in World Cup (WC) events consist of several laps around a stadium with respect to TV productions and spectators. NC and BI events are usually arranged on 2.0 – 4.0 km laps, while courses from CC races can be up to 16.7 km in individual start competitions (Table 1). Exceptions to the FIS WC rules are some stages from the Tour de Ski (2010). The longest course was 36.1 km on Stage 6, while Stage 8 was the steepest with a maximum climb of 407 m, which clearly exceeds the norms of courses. A further difference between CC, NC and BI is the competition distances performed during a World Cup season. The range in NC races is limited to either 5 or 10 km and from 7.5 to 20 km in BI. In CC skiing, sprint races are the shortest at approximately

Table 1 - Minimum and maximum competition and course lengths according to the FIS and IBU rules (FIS, 2008a; FIS, 2008b; IBU, 2010b)

	Min. Competition length (km)	Max. Competition length (km)	Min. Course (lap) length (km)	Max. Course (lap) length (km)
Biathlon	7.5	20.0	2.5	4.0
Cross Country - Sprint	1.0	1.8	0.5	1.8
Cross Country - Distance	3.8	50.0	2.5	16.7
Nordic Combined	5.0	10.0	2.0	2.5

1.2 km, with the longest competitions in the FIS WC program up to 50 km. Differences in course length lead to variations in racing speed. The range of the winning speed reaches from 6.34 ms^{-1} (30km free; La Clusaz, FRA; mass start; 18th Dec. 2010) to 9.11 ms^{-1} (1.64 km free Sprint; Drammen, NOR; prologue; 20th Feb. 2011) for the 2010/2011 season. Differences in lap length may have an effect on the general course profile, in addition to the snow and track conditions.

The primary interest of this study is to identify whether the male Norwegian national teams select skating skis with similar characteristics.

METHODS

Cross-country skating skis from the male Norwegian national teams in CC (n = 81), BI (n = 106) and NC (n = 53) from four different ski brands (C = 38, A = 187, B = 161 and D = 34) were tested under lab conditions (Figure 3). The camber characteristics were measured with the SkiSelector™ (Vendolocus Development AB, Bromma, Sweden) measurement device. Out of the span curve data, parameters such as stiffness, camber height at the balance point (*HBP*), the nominal contact length and the ski tip and tail opening characteristics were calculated. The SkiSelector™ device consists of a rigid aluminium frame with a steel plate on top where a ski is placed. The span curve is obtained by use of a height measuring sensor that travels along the ski and measures the distance between the ski base and the steel plate. The sampling rate of the height measuring sensor is 200 Hz, which results in a longitudinal resolution of about 1 mm per measurement. Camber height values below 0.1 mm were defined as contact, and each ski was loaded with the half and full body weight (*BW*) of the skier. An additional load of 40 N was added to BI athletes to compensate for the weight of their weapon. According to the usage of the skis, three categories were defined: cold, medium and warm skis. The change of camber height (in mm) when loaded from 0.5 to 1 times the *BW* was defined as dynamic response. The stiffness, k (N/mm), was defined as half the *BW* divided by dynamic response.

For the ski tip and tail opening characteristics, two points in front of and behind the balance point were chosen. The distance is equal to, ± 41.6% of the nominal ski lengths which results in 780 – 810 mm according to the actual ski length.

For the statistical analysis of the results, the SPSS Statistics (SPSS for Windows, Rel. 17.0.0. 2008. Chicago: SPSS Inc.) programme was used. The averages or differences of means from parameters of interest were compared from all three temperature categories and brands. The two-sided level of significance, P, was then calculated, the level of significance was set to $P \leq 0.05$ and highly significant was defined as $P \leq 0.01$.

RESULTS

Stiffness

The NC skiers were the lightest group with an average of 70.0 kg, though they generally used the stiffest skis (k = 251 ± 52 N/mm). CC skiers (77.2 kg) had slightly softer skis (245 ± 70 N/mm) and BI skiers (75.7 + 4 kg) had the softest ones (192 ± 52 N/mm). The difference was highly significant in the cold category and significant in the warm (Figure 1). There were no significant differences between CC and NC skis in either category, and no significant differences were found within the temperature categories from any team.

Camber height and dynamic response

BI skis demonstrated the highest camber height when loaded with half bodyweight (*HBW*) and the lowest camber height when loaded with full bodyweight (*FBW*), which resulted in the highest dynamic response. Warm BI skis reached 3.22 mm at *HBP* and a change of - 2.35 mm when loaded from *HBW* to *FBW* (Figure 2). Skis from the NC team had the smallest dynamic response in all the categories, with an average change of - 1.45 mm. There was a highly significant difference of the mean dynamic response between the BI and the CC and NC ski in the cold and warm category. A significant difference was also found between the cold CC and NC and the universal BI and CC ski.

Contact length

There was a significant difference in the total nominal contact length between skis from NC and the two other teams. NC skis had an average nominal contact of 50.8% of the total ski length, whereas CC and BI had 47.9% and 45.4%, respectively.

Opening characteristics

All three teams chose skis with a bigger opening gap on both the ski tip and tail in the warm category. Cold skis showed the flattest characteristics for all teams and categories. BI skis, which are primarily skis from brand B, revealed significantly higher opening gaps than all other skis from both CC and NC except for the CC skis from the warm category (Figure 4). There was no clear trend for skis in the medium temperature category.

Analyses made in respect to the ski brands

Ski brands were not equally represented within the three national teams, which had a major effect on the presented results. Brands C and D are part of the CC team, Brand A is the dominant brand in CC and NC, while brand B is mostly used by BI athletes (see Table 1). Brand A skis were significantly stiffer than all other skis in each temperature category with the exception of warm brand D skis (see Figure 5). On average, their stiffness was 55% higher in comparison to the others. There was no significant difference among ski brands and the three temperature categories. The camber characteristics from the four brands also demonstrated significant differences in their dynamic response (see Figure 6). Brand A skis showed the lowest camber height at *HBW* in all temperature categories as well as the smallest dynamic response between *HBW* and *FBW,* thereby resulting in the stiffest camber measurements. The highest dynamic response on average was measured for brand B skis with -2.27 mm. Brands A and B, which are the most used brands, had a significant difference in all assessed ski categories.

More detailed and combined results from Figure 5 and Table 3 can be seen in Figure 7, which presents the stiffness for all measured ski as a function of the relative nominal contact length. A wide range of both the stiffness and contact lengths can be seen, with clear differences between the two selected ski brands in this figure. A lack of correlation was observed for brand A skis, with an r^2 of 0.0039. The coefficient of determination was slightly higher for all brand B skis with 0.2051, but still not strong.

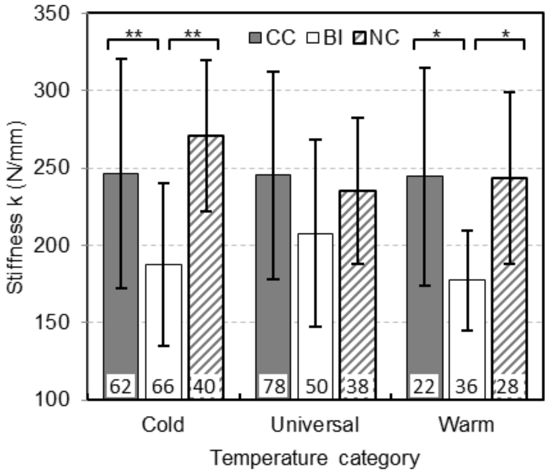

Figure 1 - Mean camber stiffness for all measured skis from CC, BI and NC split into three temperature categories. Significantly different between conditions at *$P \leq 0.05$ and **$P \leq 0.01$.

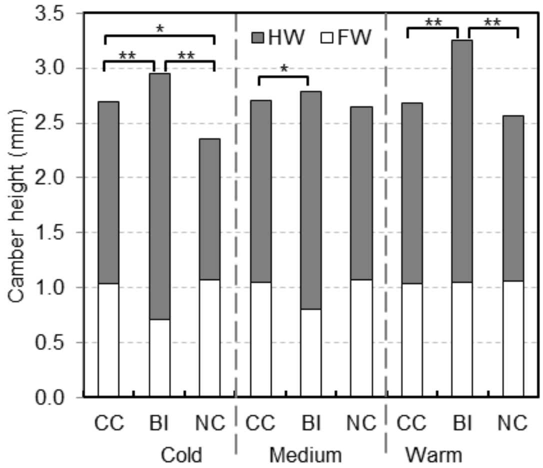

Figure 2 - Camber height at the balance point, loaded with *HBW* and *FBW* of the skiers. Significantly different between conditions at *$P \leq 0.05$ and **$P \leq 0.01$.

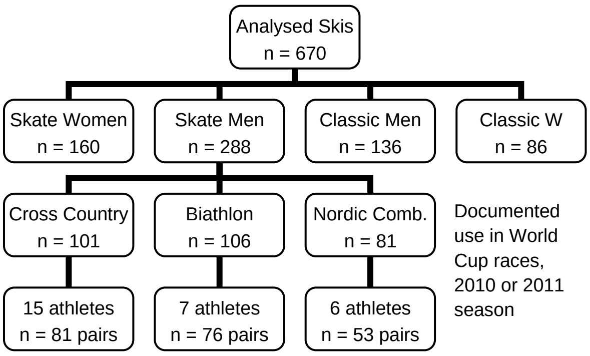

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Figure 3 - In total, 670 pairs from the Norwegian CC, BI and NC teams were analysed. Only skating skis from the men teams were considered in this study. Several analysed skis were excluded (n = 50) due to no reported use during the previous two WC seasons.

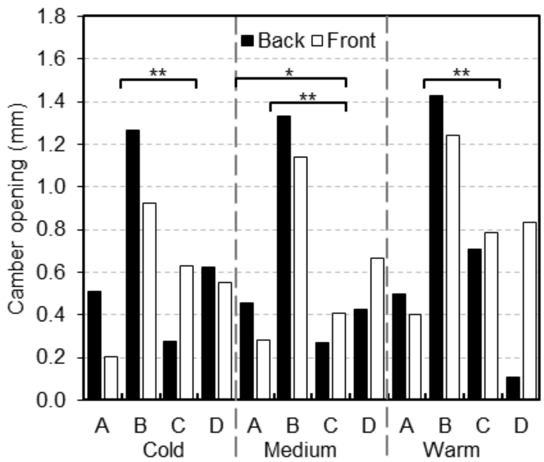

Figure 4 - Camber opening height measured with *FBW* at ± 41.6% of the ski length in front (white) of and behind (black) the *BP.* Significantly different between conditions at *$P \leq 0.05$ and **$P \leq 0.01$.

Table 2 - Number of analysed pairs from the four ski brands from each team

Ski brand	A	B	C	D
CC	40	5	19	17
BI	8	68		
NC	46	7		

Table 3 - Net contact length for the four ski brands and three temperature categories

Ski brand	A	B	C	D
Cold	49.2%	42.0%*	49.8%	42.4%
Medium	46.8%	41.0%*	46.8%	46.8%
Warm	47.0%	38.3%*	46.6%	44.6%

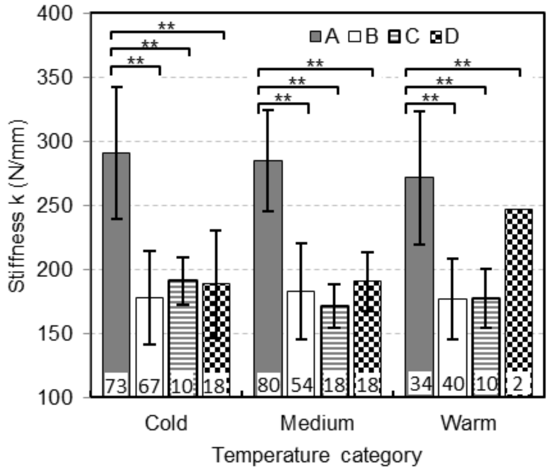

Figure 5 - Ski stiffness as a function of ski brands used by the Norwegian national teams divided into three temperature categories. Significantly different between conditions at $^{**}P \leq 0.01$.

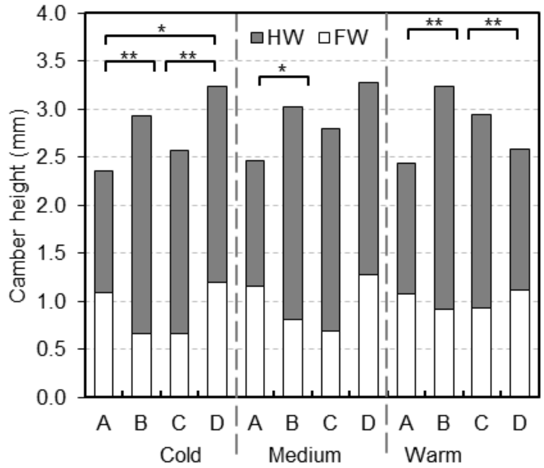

Figure 6 - Camber height measured at balance point loaded with half and full weight for all four ski brands and temperature categories. Significantly different between conditions at $^{*}P \leq 0.05$ and $^{**}P \leq 0.01$.

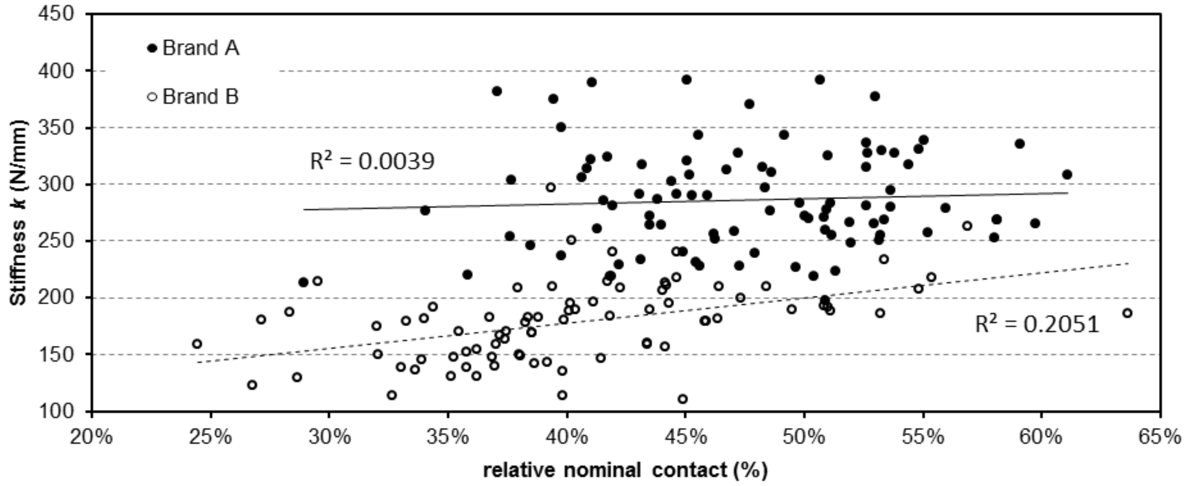

Figure 7 - Ski camber stiffness as a function of the relative nominal contact length for two selected ski brands. All measured skis are plotted. Linear regression lines are drawn in the figure.

Discussion

There are differences in cross-country ski characteristics between the Norwegian CC, BI and NC teams. The *BW* alone is not decisive enough to explain the differences between the teams in regard to ski stiffness. The ski characteristics of the teams are mostly affected by the brand's specific ski characteristics. Skis from four different brands were analysed in this study, while brands C and D are only used by the CC team. Significant differences in stiffness, camber height, ski opening height and nominal contact length were found. The influence of competition style, length or course characteristics could not be considered in this study. Moreover, there was not distinction between characteristics for certain disciplines such as sprint or long distance skiing. The skis were divided into the categories of Cold, Medium and Warm according to the suited temperature and track conditions of the skis, although this does not consider the wide variety of possible snow and track conditions.

It has been shown in previous studies that the friction only depends on the load at low temperatures (BUHL et al., 2001). Below -10ºC, the coefficient of friction is significantly higher for lower loads. A higher contact pressure leads to more heat being produced by friction, thus implying that a heavy skier has an advantage. A smaller contact area would enhance these findings, as skis investigated in this study demonstrate the opposite effect. On average, cold skis from all brands have a 7.5% longer nominal contact than Warm skis. In a more recent study, it was shown that even at higher temperatures, there was a beneficial effect for heavier skiers. The friction coefficient decreases with an increasing load, particularly at higher temperatures (BÄURLE, 2006). In real skiing, multiple factors affect the total frictional force. The variation in the relative nominal contact might possibly be explained by the great track and snow condition differences in real skiing. In addition to theoretical optimum contact characteristics, skis also have to fit to the given ski track. Skis must be stable on hard and icy tracks, as well as under soft track conditions.

A ski has to fulfil many requirements. For example, gliding experiments are often performed either under lab conditions on tribometers or on straight gliding tests in the field. In pure gliding tests, others important factors cannot be considered. In real cross-country skiing, a skier has to handle many different situations, such as steep uphills and technical downhills, on various snow and track conditions. The edging during the push-off phase will lead to torsional stresses in the ski that were not investigated in this study. In real skiing, the feeling and response from the equipment is essential. Top speed is just one of the key requirements in a selection process, with other essential characteristics being acceleration and ski stability. Athletes often talk about a “feeling”, which is hard to measure or quantify.

There is a need for more studies to investigate whether there are differences within ski characteristics between long distance and sprint athletes. Force measurements in the binding and contact pressure distribution measurements between the ski and snow surface during competitive skiing could yield interesting insights to better understand the requirements of skiing equipment.

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