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Impact on Ski Regulation Changes on Race and Gate-To-Gate Times in World Cup Giant Slalom Skiing 2005-2020

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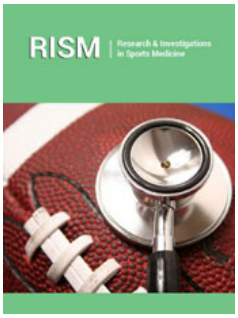

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Abstract

The International Ski Federation (FIS) implemented new ski regulation prior to the 2012/2013 season for men and women and for the men again prior to the 2017/2018 season in an effort to increase skiers' safety in the Giant Slalom (GS) event in the Alpine World Cup (WC). At present, no study has investigated how these changes impacted total race times, gate-to-gate times or number of gates per race. Hence, the purpose of this study was to investigate how the regulation changes have affected these parameters. Data were collected from the official result lists, by the FIS, for the GS event during 15 WC seasons (2005/2006-2019/2020), for men and women, respectively and grouped into Rule 1 (2005/2006-2011/2012), Rule 2 (2012/2013-2016/2017) and Rule 3 (2017/2018-2019/2020). Differences (for total race time, gate-to-gate times and number of gates) between rules were analyzed using Mann-Whitney tests and Kruskal-Wallis rank sum tests for women and men, respectively. For male skiers, the race time during Rule 2 was 152.51 (138.72-157.55) s, which was significantly slower ($p < 0.01$) than Rule 1, 147.42 (143.13-154.26) s and to Rule 3, 149.37 (135.63-158.32) s ($p<0.05$). For women, race times during Rule 1 was significant slower ($p<0.001$, $r=0.23$, $df =455$, $U=939852.5$, $z = 12.079$) than Rule 2, 141.3 (132.71-148.78) s vs. 137.12 (125.05-146.78) s. The men's gate-to-gate times increased for Rule 2 compared to Rule 3, 1.49 (1.45-1.55) s vs. 1.48 (1.45-1.52) s, $p<0.05$), whereas the women's gate-to-gate times decreased for Rule 2 compared to Rule 1, 1.53 (1.48-1.57) s, vs 1.57 (1.52-1.62) s, $p<0.001$. Changing the ski equipment regulations affected men and women differently as well the course setting and should not be considered as the sole effort to reduce skiing speed and risk of injury in GS in the alpine WC.

Keywords: Alpine skiing; Sidecut; Ski radii; Injury prevention

Introduction

There have been great changes in alpine skiing equipment over the years and the continuous development has significant effects on skiing performance [1-4]. The rapid changes in alpine ski geometry have resulted in higher skiing speeds and turning forces [5]. In relation to these changes in skiing equipment, an increased rate of injuries has been reported, and it is suggested that carving skis contribute to an increased risk of severe knee injury [6,7]. Also, previous studies [7,8] show that using skis with greater sidecut radius reduce the self-steering of the ski and also has the potential to reduce the kinetic energy in GS. The self-steering behavior of the ski and the kinetic energy are two important factors in the mechanism of anterior cruciate ligament rupture in alpine ski racing [7,9,10]. In an attempt to reduce the risk of injury in the alpine World Cup (WC), the International Ski Federation (FIS) changed the regulations for WC racing skis, prior to the 2012/2013 season [11,12].

In GS, the minimum sidecut radii of the skis changed from 23m and 27m to 30m and 35m for women and men, respectively. The ski length changed from 1.8m and 1.85m to 1.88m

and 1.95m for women and men, respectively. However, for the 2017/2018 season FIS introduced a new regulation change for racing skis was introduced by the FIS for the 2017/2018 season, where the men's sidecut radius of the GS-skis changed from 35m to 30m and the ski length from 1.95m to 1.93m, whereas the women's minimum sidecut radius and ski length remained at 30m and 1.88m, respectively [13]. Greater sidecut radius has been shown to increase turn times and reduce the average kinetic energy as well as the self-steering effect of the skis [7,8]. Haaland et al. [12] showed a lower absolute injury rate for men in the Alpine World Cup for the three seasons after the rule change, compared to six seasons before. However, no differences were seen regarding knee and other server injuries (>28 days of absence) and the authors could not draw any conclusions on the effects of the changes inside cut radii of the skis [12]. Also, it was not investigated whether the courses were set differently after the regulation changes.

Another preventive action to reduce injury rates in alpine ski racing is the course setting [14]. Previous studies [15,16] investigated the effects of changing the horizontal gate distance in GS but could not draw any conclusions on whether increased horizontal gate distance is an effective tool to reduce skiing speed and hence be a preventive measure. Gilgien et al. [17] investigated whether skier speed was governed by course setting and terrain inclination in the WC and found that in GS the horizontal gate distance increased with increased terrain inclination, which could be a way to control skier speed in steep terrain. However, skiers still ski their own individual line through the course which means that course setting changes may affect skiers differently. Also, the difference among WC skiers is often only one or a few hundredths of a second even though there are shorter sections along the courses where the differences can vary by 10 % [18,19]. In alpine skiing, a detailed performance analysis can be obtained by analyzing the time between the passing of each gate in the course (a skier's gate-to-gate times). The gate-to-gate time can be considered as the skier's tempo and changes depending on the steepness of the terrain, the skiing speed, the course setting and the skier's skill level. Thus, the gate-to-gate times vary along the course, but the skier's average gate-to-gate time for one run can be calculated as their time divided by the number of turning gates. Consequently, a skier with a longer run time will have a higher average gate-to-gate time compared to a faster skier, on the same course. Even though the average gate-to-gate time for a run is directly affected by the run time and the number of gates, it can be used as an objective parameter to compare the skiing tempo between different races as well as skiing performance. As one main purpose of the new regulations for ski equipment prior to the 2012/2013 season was reduce the self-steering behavior of the skis, which should also lower the kinetic energy. However, to the best of the authors' knowledge, no previous study has investigated whether the average race times, number of gates or skiing tempo were affected due to the regulation changes in 2012/2013 and 2017/2018.

Hence, the purpose of the present study was to analyze race times, number of gates and gate-to-gate times in WC GS racing for the seasons 2005/2006 to 2019/2020. Consequently, the authors hypothesize that the implementation of Rule 2, with a longer sidecut radii and ski lengths should decrease the skiing speed and prolong the race and gate-to-gate times compared to Rule 1 and that the implementation of Rule 3 for the men reduced race and gate-to-gate times compared to Rule 2. We also hypothesise that the implementation of the new regulations should affect the best skiers less compared to the skiers further down in the result list.

Methods

All data were obtained from the International Ski Federation's (FIS) datacenter, which is openly available in the public domain http://www.fis-ski.com. The data analysis and presentation follow strict ethical principles and do not contain any individual information in any way. Data were collected from the top 20 skiers who completed the second run of a WC event in GS between seasons 2005/2006 and 2019/2020 (n=15 seasons). For the men, a total of 116 WC races were included (n=52 for the 2005/2006-2011/2012 seasons, n=42 for the 2012/2013-2016/2017 seasons and n=22 for the 2017/2018-2019/2020 seasons). For the women, the total number of WC races was 115 (n=52 for the 2005/2006-2011/2012 seasons and n=63 for the 2012/2013-2019/2020 seasons). The different ski sidecut and length regulations are referred to as Rule 1 (sidecut; 23m for women and 27m for men, ski length; 1.8m form women and 1.85m for men), Rule 2 (sidecut; 30m for women and 35 for men, ski length; 1.88m for women and 1.95m for men) and Rule 3, which only applies for men (sidecut; 30m, ski length; 1.93m). As Rule 3 only affected men's skis, women's analyses only include Rule 1 and Rule 2. Based on the final race result, the data were extracted and clustered into three groups for men and women, respectively: position 1-3, 4-10 and 11-20. For the men, a total 1043, 842 and 442 unique finishes were included for Rule 1, Rule 2 and Rule 3, respectively. For the women, a total of 1043 and 1252 unique finishes were included for Rule 1 and Rule 2, respectively. When discussing 'men' or 'women' without group specification, it refers to the whole group - all unique finishes of the second run from position 1-20.

Statistical Analysis

The data were checked for normality using the Shapiro-Wilk test. None of the data (time, gate-to-gate times or number of gates) conformed to a normal distribution. Due to the skewed nature of the data, all results are presented as median (IQR). Correspondingly, differences (for total race time, gate-to-gate times and number of gates) between rules analysed using Mann-Whitney tests and Kruskal-Wallis rank sum tests for women and men, respectively. In situations where there was a significance, pairwise comparisons were found using a Wilcoxon rank sum test. Comparisons between two specific seasons were performed using Mann-Whitney tests. An alpha value of < 0.05 was considered statistically significant. All statistical analyses were performed using RStudio (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA. URL http://www.rstudio.com/).

Result

Between the three different rules for the men, significant differences were observed for total race time (χ^2 = 14.069, df = 2, ε^2 = 0.004, p < 0.001) and gate-to-gate times (χ^2 = 8.54, df = 2, ε^(2)= 0.003, p < 0.05) but not for the number of gates. For the men, race time during Rule 2 was 152.51(138.72-157.55) s which was significant slower (p < 0.01) compared to Rule 1, 147.42(143.13-154.26) s and to Rule 3, 149.37(135.63-58.32) s (p < 0.05). The men's total gate-to-gate time was longer for Rule 2 compared to Rule 3, 1.49(1.45-1.55) s vs. 1.48 (1.45-1.52) s (p<0.05). For all women, race times during Rule 1 was significant slower (r=0.23, df=455, U=939852.5, z=12.079, p<0.001) compared to Rule 2, 141.3(132.71-148.78) s vs. 137.12(125.05-146.78) s. The women's gate-to-gate time was longer for Rule 1 compared to Rule 2, 1.57(1.52-1.62) s, vs. 1.52(1.48-1.57) s, (r=0.35, df=3127, U=787576.5, z=18.115, p<0.001). The differences in race and gate-to-gate times were also significant for the different result groups for the women, in contrast to men who only showed significant differences between the rules as a whole group. No significant differences between the results group were observed for either men or women. All race times, gate-to-gate times and number of gates during the different regulations' periods are presented in Table 1.

Table 1: Values shown as median (IQR).

	Time (s)		
	Rule 1	**Rule 2**	**Rule 3**
Male All	147.42 (143.18-154.26) † †	152.51 (138.72-157.55) **¥	149.37 (135.63-158.32) †
Male Position 1-3	145.32 (141.44-151.85)	150.16 (135.90-154.78)	147.25 (133.99-156.45)
Male Position 4-10	146.38 (142.30-153.16)	151.11 (136.59-155.98)	148.54 (135.22-157.29)
Male Position 11-20	147.60 (143.67-154.09)	152.40 (138.98-156.85)	149.57 (136.00-158.24)
Female All	141.30 (132.71-148.78) †††	137.12 (125.05-146.78) ***	-
Female Position 1-3	138.55 (130.70-146.74) †††	136.49 (122.73-144.82) ***	-
Female Position 4-10	139.45 (131.79-147.95) †††	137.49 (123.85-146.00) ***	-
Female Position 11-20	141.19 (132.85-149.24) †††	138.39 (124.83-147.20) ***	-
	Gate-to-gate time (s)		
	Rule 1	**Rule 2**	**Rule 3**
Male All	1.48 (1.45-1.54)	1.49 (1.45-1.55) ¥¥	1.48 (1.45-1.52) ††
Male Position 1-3	1.46 (1.42-1.52)	1.47 (1.43-1.52)	1.46 (1.43-1.49)
Male Position 4-10	1.47 (1.44-1.53)	1.48 (1.44-1.54)	1.47 (1.44-1.51)
Male Position 11-20	1.48 (1.45-1.54)	1.49 (1.45-1.55)	1.48 (1.45-1.52)
Female All	1.57 (1.52-1.62) †††	1.53 (1.48-1.57) ***	-
Female Position 1-3	1.55 ± (1.50-1.60) †††	1.51 (1.46-1.54) ***	-
Female Position 4-10	1.57 1.51-1.61) †††	1.52 (1.48-1.56) ***	-
Female Position 11-20	1.58 (1.52-1.62) †††	1.53 (1.49-1.57) ***	-
	Number of Gates		
	Rule 1	**Rule 2**	**Rule 3**
Male	50 (48-51.5)	50.5 (47-52)	51 (47-55)
Female	44.5 (42.5-48.5) †††	44 (41.5-48) ***	-

n=number of unique finishes

*vs. Rule 1, p<0.05; † vs. Rule 2, p<0.05; ¥ vs. Rule 3, p<0.05

**vs. Rule 1, p<0.01; †† vs. Rule 2, p<0.01, ¥¥ vs. Rule 3, p<0.01

***vs. Rule 1, p<0.001; ††† vs. Rule 2, p<0.001.

For the men, the race time during the first season with Rule 2 (season 2012/2013) were significantly shorter compared to the previous season with Rule 1 (season 2011/2012), 153.04(148.16-158.74) s vs. 155.52 (147.31-162.61) s, (r=0.2 U=20681.5, z=6.209, p<0.001), whereas the first season with Rule 3 (season 2017/2018) was significant shorter compared the previous season with Rule 2 (season 2016/2017), 148.8 (137.06-159.28) s vs. 146.61 (135.90-153.70) s, (r=0.174, U=16865.5, z=-1.883, p<0.01,). No significant difference between the last season with Rule 1 (season 2011/2012) and the first season with Rule 2 (season 2012/2013) was found for the women. All race times and number of gates per season for men and women are presented in Figure 1A-B.

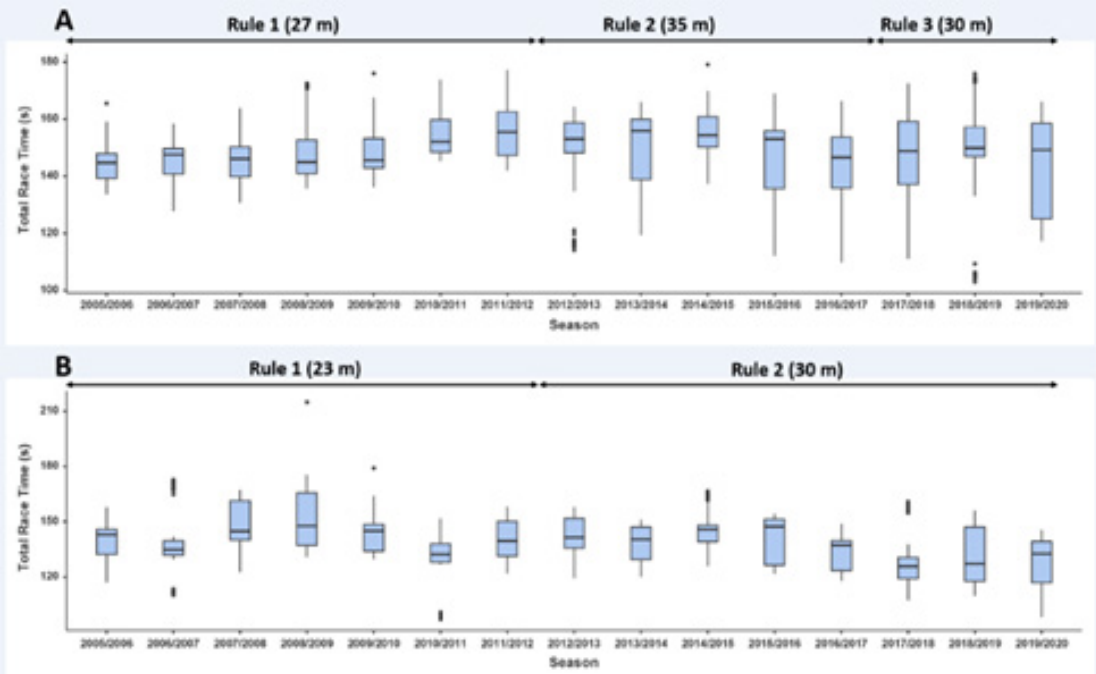

Figure 1A-B: All median race times and number of gates per season for men (A) and women (B). The arrows show the timespan for each rule and with the minimum ski sidecut radius.

Discussion

This is the first paper investigating how the different sidecut regulations, which were introduced for the 2012/2013 and 2017/2018 seasons, have affected race times, number of gates and gate-to-gate times in World Cup giant slalom. The results show that the implementation of Rule 2, which increased the minimum sidecut in GS from 23m to 30m and from 27m to 35m, for women and men respectively, significantly increased the race times for men compared to Rule 1 and Rule 3, which verifies the authors' hypothesis. However, in contradiction to our hypothesis, the women's race times got significantly shorter with Rule 2, compared to Rule 1 and where all position groups had significantly shorter race and gate-to-gate times during Rule 2 compared to Rule 1, whereas only all men as a whole group showed significant differences with either Rule 2 or Rule 3. Also, in contradiction to our hypothesis, no significant differences between different result groups for the different rules were observed, nor for the men's gate-to-gate times between Rule 1 and Rule 2.

The purpose of the new sidecut regulation for the 2012/2013 season was to decrease the number of knee injuries by reducing the self-steering behavior and aggressiveness of the GS-skis, as these are factors affecting the risk to sustain a knee injury [7,9]. Furthermore, [8] and Gilgien et al. [20] suggest that skiing speed should be reduced to decrease the kinetic energy and reaction forces on the skier while skiing to further reduce the risk of injury. The present study shows that the implementation of Rule 2 with longer sidecut radii and ski lengths increased the overall race times for the men during the seasons with Rule 2 but had the opposite effect on the women's race times. One possible explanation to the shorter race times for women after the implantation of Rule 2 is the reduced number of gates used during Rule 2 compared to Rule 1. Fewer gates result in fewer turns and longer distances between each turn, which could indicate that straighter course settings after the introduction of Rule 2. However, longer distances between turns does not automatically mean straighter courses as the horizontal distances between the gates could be increased and consequently increasing the total skied distance. Still, it is likely that the shorter racing and gate-to-gate times with introduction of Rule 2 are caused by fewer gates with longer distances between the gates and straighter courses as greater sidecut radii are reported to reduce skiing speed and increase turn time [8].

Interestingly for the men, no difference in gate-to-gate times was observed between Rule 1 and Rule 2, even though the total race times were longer with Rule 2 and the number of gates were the same. This suggests that the average course settings were changed as a result of the introduction of the new regulations. Still, previous studies [18,21,22] have shown that skiers use different line and turning strategies and that the skiing performance is more related to minimizing energy dissipation along the course compared to the center of mass trajectory and skiing line. For the men, Rule 2 resulted in longer race times compared to both Rule 1 and Rule 3, suggesting that the minimum sidecut of 35m during Rule 2 significantly slowed down the skiing speed. Interestingly, for the men, the first season with Rule 2 had shorter race times compared to the last season with Rule, whereas there was no significant difference for the women. However, the first season with Rule 3 had longer race times compared to the last season with Rule 2. These season-to-season variations are difficult to explain and could depend on several different factors e.g., different course settings, snow conditions and course preparations. However, the present

results suggest that it is difficult to anticipate the outcome when implementing new equipment regulations as it is clear that men and women are affected differently as well as there are differences between each season.

The men's Rule 3 have the same minimal sidecut as the women's Rule 2(30m) and the ski lengths are similar as well, 1.93m for men and 1.88m for women. As the women's race time decreased with Rule 2 compared to Rule 1 and the men's race time decreased with Rule 3 compared to Rule 2, one can speculate that a sidecut and ski length around 30m and 1.9m, respectively, are beneficial for GS performance in the WC, especially for women. However, the reason of the improved performance remains unclear, but it is likely that skiing tactics change with increased sidecut radii and ski length, and that the velocity barrier plays a major role [8]. To avoid mistakes, all skiers need to dissipate excess kinetic energy at certain points along a course. This intuitive action and control of speed is called the velocity barrier and is individual but is also affected by factors such as the inclination of the slope, course setting, sidecut radius and ski length [8,19,20].

Haaland et al. [12] showed a reduction in overall rate of injuries but not specifically for lower extremity injuries, three years after the implementation of Rule 2. However, they only had access to three years of injury data with Rule 2 which restricted their ability to draw conclusions of the effects of the equipment change due to the limited statistical power. To the best of the authors' knowledge, no studies exists where the more long-term effects have been investigated or the difference in injury rates between Rule 2 and Rule 3 for the men. If the shorter race times are explained by higher skiing speed, it is likely that reaction forces on the skiers increase as well, which could increase the risk of injuries [20]. Even though the increased ski radii and ski lengths might increase skiing speed, they are also likely to reduce the self-steering behavior or the skis, which is reported to reduce the risk of lower extremity injuries [8,9]. Hence, future studies are needed to investigate the long-term effects of the different equipment changes and whether the aim of reducing lower extremity injuries was reached or not.

Conclusion

The increased minimum ski radii and ski length which were implemented prior to the 2012/2013 WC season, affected male and female skiers differently. For female skies, the total race time, gate-to-gate time and number of gates decrease after the implementation of the new regulations, whereas for the men, the total race time and gate-to-gate time increased. However, the men's second regulation change, prior the 2016/2017 season, reduced race times and gate-to-gate times, whereas the number of gates increased. Hence, changing the ski equipment regulations affect men's and women's performance differently as well the course setting, and should not be considered as the sole effort to reduce skiing speed and risk of injury in GS in the alpine WC.

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