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The contribution from cross-country skiing and shooting variables on performance level and sex differences in biathlon World Cup individual races

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Abstract

Biathlon is an Olympic winter sport where rifle shooting and cross-country skiing is combined in various race formats. In the individual distance (15 km for women and 20 km for men), athletes compete over five laps of skiing with shooting between each lap (i.e., 4 shootings). The aim of the current study was to compare total race time differences, as well as the contribution from cross-country skiing and shooting variables to this difference, between biathletes of different performance-levels and sexes in individual races in the biathlon World Cup. Based on publicly available race reports, we compared these factors between top-10 results (G1-10) and results within rank 21-30 (G21-30), as well as the corresponding sex differences. G21-30 among men/women were on average 4/6% behind G1-10 in total race time, in which course time accounted for 42/54% of the overall performance difference, followed by 53/44% explained by penalty time caused by shooting performance (i.e., the number of hits). The remaining 2-3% was explained by differences in shooting time and range time. Women G1-10 were on average 15% slower in skiing speed than men G1-10, which accounted for 92% of the overall performance difference between sexes. In total among G1-10, men shot on average 15 seconds faster than women and total penalty time was 18 seconds shorter. In conclusion, course time and penalty time contributed approximately equally to the performance-level differences whereas course time explained above 90% of the sex differences in individual World Cup biathlon races.

Key words: competition analysis, endurance performance, gender difference, rifle shooting, XC skiing

Introduction

Biathlon is an Olympic winter-sport where three or five 0.8-4 km laps of cross-country skiing using the skating technique is interspersed with 5-shot-series of rifle shooting, alternating between the prone or standing position. One of the traditional racing formats is the individual distance, consisting of five laps of 3 km (women) or 4 km (men) skiing, with 4 series of shooting and a penalty time of one minute added for each missed shot. In comparison, the biathlon sprint distance is 10 and 7.5 km in total for men and women, respectively, and includes two shootings and a 150-m penalty loop (22-24 seconds) for each missed shot at the shooting range.

In a recent study of biathlon World Cup sprint races, we found that the performance level differences between those finishing top 10 (G1-10) and those finishing between 21st and 30th place (G21-30) were 3-5% in both sexes for the total race time.[1] In that study, the performance level differences in cross-country skiing time (course time) were 2-3% in both sexes, which explained 59-65% of the total time difference between groups. In comparison, penalty time explained 31-35% of the group difference in both sexes, whereas the remaining 4-6% was explained by the time spent at the shooting range (i.e. range time and shooting time). Such extensive analyses over several World Cup seasons has not yet been performed for the individual distance, although analyses of the 2001/2002 World Cup season showed higher correlations between shooting performance and total race time in individual compared to sprint races.[2] That study indicated that shooting performance has a larger influence on overall biathlon performance in individual races than in sprint races, which can mainly be explained by a larger effect of each penalty. This higher importance of shooting performance in individual races could also lead to more conservative shooting and range times in individual races. When expressed in percentage of the winner's total race time, one penalty has previously been shown to equal 1.6-2.0% in the individual distance and 1.3-1.6% in sprint races among men.[2] However, it is still unclear how much of the overall performance in individual races that is explained by course time and shooting variables.

In our previous study on biathlon World Cup sprint races, we found no sex difference in shooting performance,[1] which is in line with findings from Olympic rifle shooting.[3] However, men shot on average 6 s faster than women in total, which was hypothesized to be caused by higher risk-taking and competitiveness as well as shorter overall time differences between athletes among men. None of these aspects have yet been investigated for the individual distance at a large scale.

Therefore, the aims of the current study were to compare total race time differences, and the contribution from cross-country skiing and shooting variables to this difference, in individual races in the biathlon World Cup. Specifically, we aimed to analyze the relative contribution of course time, shooting performance (i.e., penalty time), shooting time and range time to the total race time in both men and women during 2011/2012 to 2015/2016 seasons. We hypothesized that 1) shooting performance would explain a larger part of the overall differences between performance groups than previous findings in biathlon sprint races, 2) that no sex difference in shooting performance would be present, and thus 3) course time would almost entirely explain the differences between men and women.

Methods

All analyses were based on publicly available race reports from the International Biathlon Union (IBU) datacenter (2016), and permission to use the data for scientific purposes was given by the IBU. G1-10 and G21-30 in all 15 biathlon individual races during the 2011/2012 to 2015/2016 World Cup seasons were compared on total race time, course time, shooting time, and range time, as well as shooting performance (penalty time). This is the same method as previously described in detail in a recent paper on the sprint distance.[1] The reasons for choosing G1-10 and G21-30 as performance groups within both sexes were primarily that these groups are clearly separated in performance and that the lower performance group is still motivated to give full effort since a top-30 result gives more than 10 World Cup points. Total race time refers to the total finish time of the competition, including course time, shooting time, range time, and penalty time. Course time is the time spent skiing, excluding time at the shooting range and penalty time. Range time refers to the time at the shooting range, excluding shooting time. Shooting time is the amount of time spent at the shooting mat in all four shootings together, measured manually by the IBU officials at the shooting range. Penalty time is given as one minute added time for each missed shot at the shooting range. Course speed was calculated from the reported race distance in each race minus 400 m (due to the length of the shooting range) and divided by course time. The pacing analysis was based on course times on each lap, calculated from the official split times provided by the official time keeping system in biathlon World Cup races (Siwidata GmbH, Merano, Italy). Course time was normalized for race distance (i.e., skiing speed) to allow for comparisons of the relative contribution of course, penalty, range, and shooting times on total race time differences between men and women. In addition, the performance of individual shots (i.e., relative miss rate to the total amount of mistakes in shots 1–20) were analyzed for both groups in both sexes.

The average race distances were (men; women, mean±SD) 20164±410 m; 15159±252 m. The height differences from the lowest to the highest point in the course were 49±12 m; 43±10 m, the highest climbs (altitude difference) were 37±12 m; 33±10 m and the total climbs were 721±84 m; 543±62 m. The average wind speeds (1.3±1.1 m/s; 1.1±0.6 m/s for men and women), the average air temperatures (2.2±3.6 ºC; 0.5±3.6 ºC) and average snow temperatures (0.3±0.5 ºC; –0.5±0.9 ºC) were measured 30 min after the first start in each competition.

Statistical analyses

Statistical analyses were performed using SPSS Statistics version 22 (IBM Corp., Armonk, NY, USA). Variables were tested for homogeneity of variances in both groups using Levene's test, tested for normality and, if not otherwise noted, presented as mean and standard deviation (SD). Unusual cases were filtered out using the "detect unusual cases" function in SPSS on the main variables of course time, penalty time, shooting time, and range time with the race ID serving as case identifier. Cases with an Anomaly Index above 2 were filtered out before applying the main analyses. This filtering of extreme values removed 1 result among G1-10 and 3 results among G21-30 in both sexes. A more conservative filter than that used for the main variables was applied for the shooting time analysis of individual shots, which removed 8 and 11 results among men and 12 and 14 among women out of the 150 results for each category. Results with shooting times of less than 6 s or above 30 s to the first shots and/or shooting times of less than 1 s or above 10 s between shots were removed from the shooting time analyses of individual shots. The conservative filters on shooting times on individual shots removed extreme shooting times, probably affected by wind or mistakes by the athlete. These filters did not affect the conclusions on individual shots, but they affected the mean shooting times to a small extent and we therefore chose to use the results with filters in the analyses. Independent samples t-test was used to test for significant differences between the G1-10 and G21-30 groups, as well as for sex differences regarding total race time, course time, penalty time, shooting time, and shooting performance. In addition, repeated measures ANOVAs were used to test the effect of performance level and sex on pacing and shooting times on individual shots. In addition, odds ratios for mistakes on individual shots between men and women were calculated.

Results

On average, men G21-30 were 4.3% behind G1-10 in total race time (Table 1 and Figure 1). The average difference in course time explained 42% (i.e. 55 s out of an overall 131 s group-difference), whereas penalty time accounted for 53% and shooting time 3% of the total race time difference between groups among men. The remaining time difference was explained by small, non-significant, group differences in range time. On average, women G21-30 were 5.5% behind G1-10 in total race time (Table 1). The average difference in course time accounted for 54%, penalty time 44%, and range time 2% of the total race time differences between groups among women. Shooting time did not differ between groups among women.

In absolute differences, G21-30 was on average 2-3% behind G1-10 in course time and missed approximately 1.1-1.2 more shots in each race in both sexes. The extra missed shot in each competition by G21-30 compared to G1-10 led to 50% and 43% shorter penalty times in G1-10, among men and women, respectively.

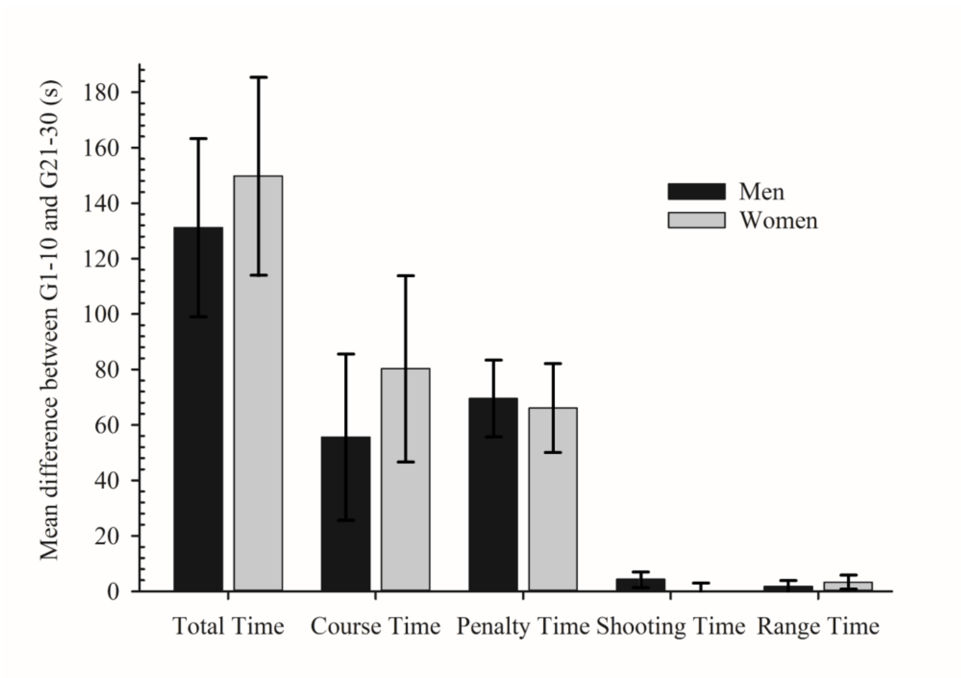

Figure 1. Mean difference (± 95% CI) between top-10 performers (G1-10) and those finishing among rank 21-30 (G21-30) in total race time, as well as the time lost in course time (the time spent skiing, excluding time at the shooting range and penalty time), penalty time (the time added to total time as a consequence of shooting performance), shooting time (the

total time spent shooting) and range time (the time at the shooting range, excluding shooting time) in both sexes in 15 Biathlon World Cup individual races during the 2011/2012 – 2015/2016 seasons.

The comparisons of course time across laps, showed a significant effect of lap number ($F_{4,149}$=211, p<0.01) and performance level ($F_{4,147}$=4.7, p<0.01), but no effect of sex ($F_{4,149}$=0.23, p=0.92) on lap times. The first lap was fastest, with increasingly slower lap times for each lap until the last lap that was faster than the fourth lap, but not significantly different than the third lap within both sexes (Figure 2). G1-10 skied on average closer to their average speed on the first, second and last lap compared to G21-30 among men, whereas G1-10 among women only skied the first lap significantly closer to the average speed compared to G21-30 (p<0.01).

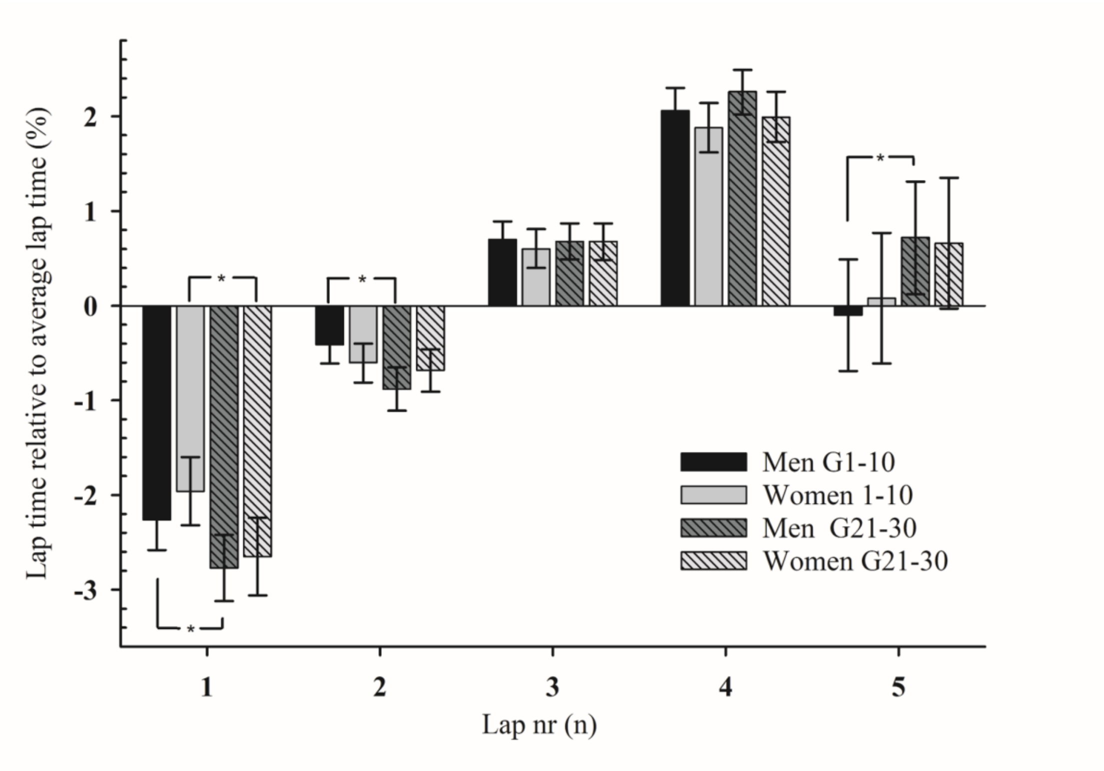

Figure 2. Lap time on each of the five laps (mean ± 95% CI) as a percent of the mean lap time (based on three equal split times from each lap, excluding the final sprint) among men and women top-10 performers (Men G1-10 and Women G1-10) and those finishing among rank 21-30 (Men G21-30 and Women G21-30) in 15 Biathlon World Cup individual races

during the 2011/2012 – 2015/2016 seasons. * = significant difference between performance-groups within sexes.

G1-10 women were 15% behind G1-10 men in total race time when course time was normalized for course distance (p<0.01). The average sex difference in skiing speed of ~15% accounted for 92% of the performance difference between sexes, whereas penalty time, shooting time, and range time accounted for 4%, 3%, and 1%, respectively (all p<0.01).

Table 1. Total race time, course time, speed, shooting time, range time, penalty time and shooting performance in Biathlon World Cup individual races during the 2011/2012 - 2015/2016 seasons for top-10 performers in each race (G1-10) and those finishing among rank 21-30 (G21-30) in both sexes.

	Men ($\overline{X}$ ± SD)		**Women ($\overline{X}$ ± SD)**	
	G1-10 N = 149	G21-30 N = 147	G1-10 N = 149	G21-30 N = 147
Total race time (s)	3076 ± 145^{YY}	3207 ± 136**	2741 ± 155	2890 ± 158**
Course time (s)	2805 ± 136^{YY}	2860 ± 125**	2431 ± 140	2511 ± 152**
Speed (m/s)	7.15 ± 0.41^{YY}	7.01 ± 0.40**	6.09 ± 0.40	5.90 ± 0.40**
Shooting time (s)	115.0 ± 11.6^{YY}	119.3 ± 12.7**	130.1 ± 13.6	130.1 ± 12.5
Range time^{X} (s)	87.7 ± 9.2^{YY}	89.4 ± 10.5	92.8 ± 10.4	96.1 ± 10.4**
Penalty time (s)	68.9 ± 48.5^{YY}	138.4 ± 70.1**	86.6 ± 60.2	152.7 ± 77.6**
Hits (%)	94.3 ± 4.0^{YY}	88.5 ± 5.8**	92.8 ± 5.0	87.3 ± 6.5**
Time prone1 (s)	30.0 ± 4.3^{YY}	30.8 ± 3.9	32.6 ± 4.0	33.0 ± 3.9
Time standing1 (s)	26.0 ± 3.6^{YY}	27.5 ± 4.0**	30.9 ± 4.9	30.6 ± 5.2
Time prone2 (s)	31.9 ± 4.1^{YY}	32.7 ± 4.5	34.4 ± 4.5	35.4 ± 3.8
Time standing2 (s)	27.0 ± 4.3^{YY}	28.2 ± 4.8*	31.1 ± 5.4	31.0 ± 5.4
Hits prone1 (%)	95.6 ± 8.7	91.2 ± 12.2**	94.4 ± 10.7	90.6 ± 13.9*
Hits standing1 (%)	93.0 ± 10.9	87.5 ± 12.9**	91.3 ± 11.7	84.8 ± 15.8**
Hits prone2 (%)	95.3 ± 9.7	91.4 ± 12.6**	95.3 ± 9.4	89.8 ± 13.7**
Hits standing2 (%)	93.2 ± 11.3^{Y}	83.8 ± 15.4**	90.2 ± 12.9	84.0 ± 16.8**

^{X}Time at the shooting range excluding shooting time; * = Significant difference between performance groups within sexes (*p < 0.05, ** p < 0.01); ^{Y} = sex difference among G1-10 (^{Y} p < 0.05, ^{YY} < 0.01)

The repeated measures ANOVA showed a significant effect of sex on the shooting times on individual shots in both G1-10 ($F_{19,140}$=32.1, p<0.01; Figure 3) and G21-30 ($F_{19,137}$=20.7, p<0.01). Contrast analyses revealed that during both prone shootings, women G1-10 used 9-15% longer time than men G1-10 on the three middle shots, as well as 11-24% longer time between all shots during standing shooting. On average, women G1-10 used 20% longer time than men G1-10 on the first standing shooting and 14% longer time on the last standing shooting. The largest absolute sex difference in shooting time on individual shots were 1.4 and 1.7 s from entering the shooting mat to the first shots for both standing shootings.

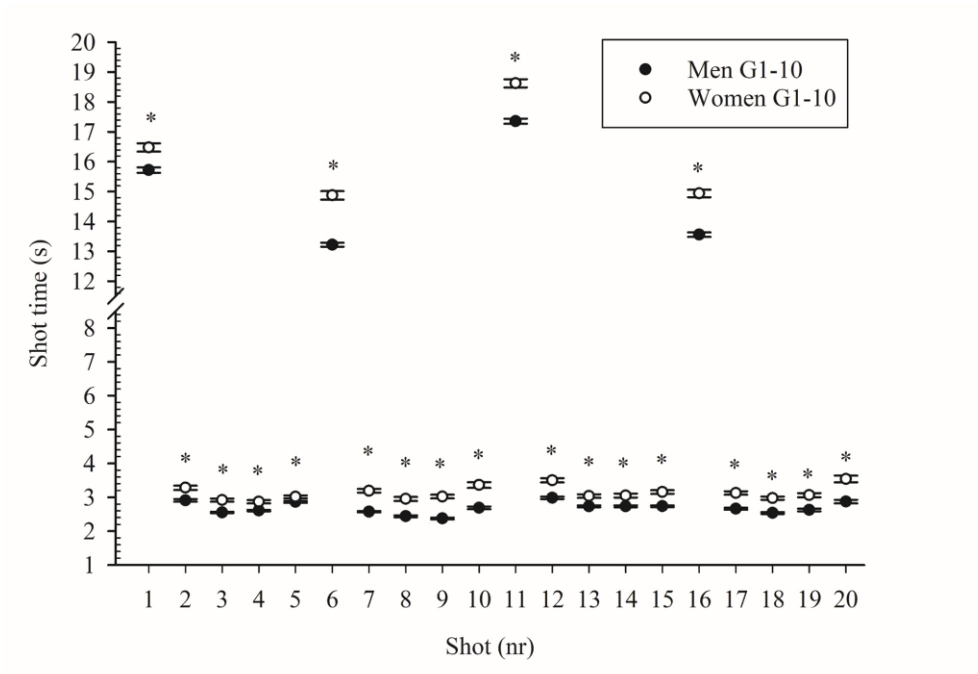

Figure 3. Shooting times (mean ± 95% CI) for individual shots among top-10 performers (G1-10) in both sexes in 15 Biathlon World Cup individual races during the 2011/2012 – 2015/2016 seasons. Shots 1-5 and 11-15 are prone shooting, 6-10 and 16-20 are standing. * = sex difference p<0.01

Men and women G1-10 missed 0.6 times less shots during prone compared to standing shooting (Figure 4). During both prone shootings, men G1-10 missed on average the first shot ~2 times more often than other shots during prone, whereas women G1-10 missed shots 2-5 twice as often as shot one during prone shooting. The 7.4%-point better shooting performance among men G1-10 compared to G-21-30 in standing was significantly larger than the 4.1%-point better shooting performance in prone (p<0.01). Among women, the proportion of the hits between G1-10 and G21-30 for standing (6.3%-point) did not differ from prone shooting (4.7%-point, p=0.26). In addition, men G21-30 shot on average 5.6%-point better in prone than standing, which was larger than the 2.3%-points better shooting performance in prone among G1-10 ($p<0.01$). This performance level difference in prone vs. standing shooting performance did not occur among women ($p=0.32$). G1-10 and G21-30 among women hit 4.1 and 5.9%-points more in prone shooting than standing ($p<0.01$).

The odds ratio of a mistake on the first shot during prone in men versus women was 2.6 (95% CI 0.95–7.11) for the first shooting and 3.0 (95% CI 0.99–9.09) for the second prone shooting. The corresponding odds ratio for 3rd shot of the first prone shooting was 0.3 (95% CI 0.08-0.96) and for the 4th shot of the second prone shooting was 0.2 (95% CI 0.05–0.89). In addition, the odds ratios of a mistake on the first and last shot of the second standing shooting in men versus women was 0.6 (95% CI 0.30–1.07) and 2.1 (95% CI 1.06-4.13), respectively.

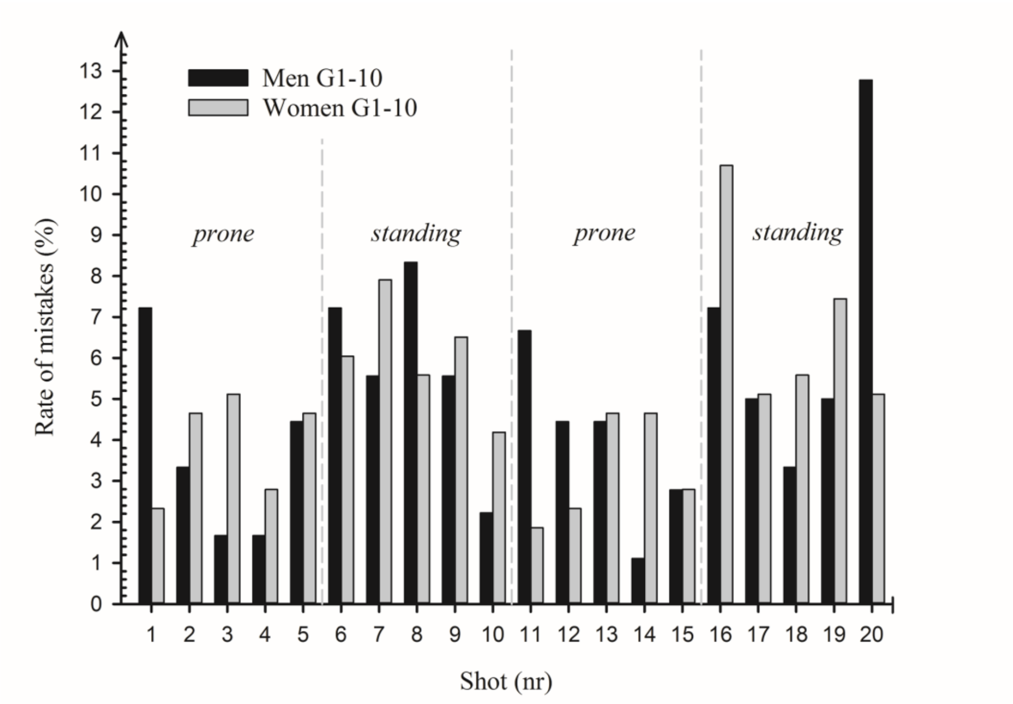

Figure 4. Rate of mistakes per shot among men and women top-10 performers (Men G1-10 and Women G1-10) in 15 Biathlon World Cup individual races during the 2011/2012 – 2015/2016 seasons. Shot 1-5 and 11-15 prone, shot 6-10 and 16-20 standing

Discussion

In the current study, we compared total race time differences, as well as the contribution from cross-country skiing and shooting variables to this difference, between biathletes of different performance-levels and sex in individual races of the Biathlon World Cup 2011/2012 to 2015/2016. Course time accounted for 42 and 54% and penalty time (i.e. shooting performance) accounted for 53 and 44% of the performance-level differences among men and women, respectively. The remaining difference of 2-5% was explained by shooting time among men and range time among women. With course time normalized to course distance, we estimated that women were on average 15% behind men among G1-10, with the cross-country skiing speed explaining more than 90% of this sex difference. Among G1-10, men had on average 18 s less overall penalty time than women and shot on average 15 s faster than women.

Performance-level differences

The overall performance level differences of 4-5% in both sexes were mainly explained by course time differences (56-80 s) and penalty time [slightly above 1 missed target more (i.e., 66-70 s)]. Altogether, 95–98% of the performance difference between G1-10 and G21-30 biathletes are explained by course time and shooting performance (i.e., penalty time) in both sexes, whereas the remaining differences were explained by shooting time (3%) among men and range time (2%) among women. This high importance of course time and shooting performance is in line with previous studies in biathlon sprint races[1], and the findings by Rundell & Bacharach[5] who found that shooting performance and skiing time in an individual race explained 97% and 94% of the variance in national rank among male and female American biathletes, respectively. In addition, Skattebo et al.[4] showed that the intraclass correlation coefficient in shooting time is lower (0.49-0.63) than for skiing time (0.90-0.91), meaning that the differences between athletes in shooting time is low in respect to each athlete's individual variability from race to race. Hence shooting time does not differentiate athletes of different levels as much as skiing time in sprint races. The same authors found that the smallest worthwhile performance enhancements of skiing speed were 0.82% in men and 0.97% in women and approximately 40% for shooting time.[4] Thus, our data and other studies reveal that shooting time and range time differences between the G1-10 and G21-30 have no or much lower impact on the overall individual race performance than skiing speed and shooting performance in both sexes.

The 95% confidence intervals indicated course time and penalty time as relatively equally important in individual races in both sexes. This reveals a greater influence of shooting performance than the 31-35% of the overall performance difference between G1-10 and G21-30 explained by shooting performance in World Cup sprint races.[1] Furthermore, this corresponds to previous findings using correlations for a single season in the Biathlon World Cup.[2] This larger influence of shooting performance is mainly explained by the 1-minute penalty time which is added to the total time for each missed shot in individual races compared to the 22-24 s extra time because of the penalty loop in sprint races.[1] In addition, the individual race has twice as many shootings as sprint races, altogether creating a 2.6 times larger impact from shooting performance on the total time in individual races compared to sprint races when the relative number of misses are the same. Therefore the doubled track length does not fully compensate for the increased impact from shooting performance. This explains why, for both sexes, shooting performance explains more of the performance difference between G1-10 and G21-20 in individual races compared to sprint races.

Shooting performance

The average hit rates among G1-10 were 94.3 and 92.8%, whereas G21-30 hit on average 88.5 and 87.3% among men and women, respectively. Thus, there is a sex difference of 1.6% in overall shooting performance between men and women G1-10, which is mainly explained by a significant sex-difference in the last standing shooting where men's G1-10 hit rate is 3.3% higher than women's. The reason for this is currently unknown but the difference is small (about one missed target every third race) and considering that there is no sex difference found in Olympic rifle shooting,[3] military marksmanship,[6] or in biathletes in the sprint distance,[1] we regard this finding as interesting but very small. The hit rates found in this study correspond to the hit rates in sprint races of 92-93% and 85% in G1-10 and G21-30, respectively, in both sexes.[1]

The higher importance of shooting performance rather than course time on total time in individual races compared to sprint races apparently did not lead to more conservative shooting times among men and women in individual races. Shooting times averaged around 30 s and 26-27 s among men versus 32-35 s and 30-31 s among women in prone and standing, respectively, which is similar to corresponding data from sprint races[1]. Furthermore, Skattebo et al.[4] showed that biathletes in sprint races had an equal race-to-race variability in shooting performance and skiing time expressed in seconds (~18-23 seconds), but only 3.5-4.5 seconds in shooting time, indicating a lower importance of shooting time than skiing speed and shooting performance on the overall performance. Furthermore, the performance level difference in shooting performance was lower for prone shooting than for standing shooting among men, but not among women. This means that men G21-30 lose significantly more time due to mistakes in standing vs. prone shootings compared to G1-10, whereas the differences are the same between performance levels on both shooting positions among women.

Individual shots

The sex difference in shooting performance, with men missing more than women on the first shot during both prone shootings, did not occur for standing shooting. However, the reason for this sex difference on first shots of prone shooting is unclear and should be investigated further with a different study design (i.e. an experimental setup). Furthermore, men missed the last shot on the last standing shooting three times more often than other standing shots, whereas women did not. In total, 13% of the mistakes among men G1-10 occurred on the last shot of the last standing, whereas women missed the first shot during the last standing almost twice as often as men and other standing shots within women G1-10 in the competition (i.e. 10% vs 5% of the total missed shots). Why these sex-differences in hit rate during the last standing occurs is currently unclear. Possible explanations for more men missing the last shot are more men competing for the podium at the last shooting compared to women, which is supported the 1.5 times larger miss rate than men G21-30, or that women in general take fewer risks than men.[11] However, why women G1-10 miss the first shot of the last standing almost twice as often as men, even though they shoot slower, is unclear and needs to be examined further.

Pacing

There is a significant difference in pacing between the two performance levels on the first, second and last of the five laps among men and on the first lap among women. G1-10 skied these laps closer to their average speed in the competition than G21-30 in both sexes. These findings are in line with those from cross-country skiing where better performing groups of skiers use more even pacing in men's 15 km and women's 10 km individual races both in the classical and skating styles.[12] On average, both men and women in both of our performance groups completed the races with a J-shaped pacing with each of the four first laps being consequently slower, but skied the last lap equally fast as lap 3. Hence, it seems that biathletes ski the complete last lap faster, which is different to cross-country skiers who employ a clearer positive pacing strategy through the entire race. This can probably be explained by more maintenance of energy in early- and mid-parts in the race among biathletes, in order to optimize shooting performance on all four shootings, followed by maximal effort during the last lap.

Men skied on average 15% faster than women which is slightly more than in biathlon World Cup sprint races where we found an average sex-difference of 12% during the same years[1] and yet at little larger than found in previous studies in cross-country skiing[13,14] and most other endurance sports[15]. In addition, there is a sex-difference in pacing only on the first and the last lap, where men ski these laps closer to their average speed compared to women in both performance groups. However, the sex difference is relatively small and both groups seem to apply approximately the same pacing strategy. In sprint races, we previously found no sex difference in pacing whereas previous research in cross-country skiing found that men skied closer to their average speed on each lap compared to women.[12] In marathons however, there is no sex difference in pacing among elite runners,[16] and longer distances in various sports seem to diminish the sex differences in performance[17] and pacing.[18] Thus, it is unlikely that the double distance in individual races compared to sprint races explains the small sex difference in pacing found here.

Conclusions

Course time and shooting performance were the most performance differentiating factors between G1-10 and G21-30 in both sexes in individual races in the Biathlon World Cup. These factors contributed almost equally to the total time difference between performance groups, which indicates a larger influence of shooting on the overall individual race performance compared to previous findings in the sprint discipline. Overall, men skied on average 15% faster and shot 1.6% better and 12% faster than women, indicating a sex difference on all components of Biathlon individual race performance.

Practical Applications

The current study provides benchmark values for the requirements in being top-10 of individual races in the biathlon World Cup. For example, male and female biathletes ranked between 21-30th place are on average 4% and 6% behind top 10-athletes in overall performance, with skiing speed differences between groups being 2% and 3% in men and women, respectively. Since course time and shooting performance differences explain almost the same amount of the performance level differences, these two factors seems equally important to improve in order to improve individual race performance. Furthermore, optimization of the pacing strategy, by skiing closer to the athletes' own average speed on the first lap, can benefit biathletes' performance in the individual distance. Our results also indicate that lower performing biathletes in particular should improve their standing shooting and that women in general could benefit from shooting faster.

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