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MASTER THESIS IN HUMAN MOVEMENT AND SPORT SCIENCES

ANALYSIS OF ELITE MALE AND FEMALE BIATHLON PERFORMANCES (2009/10 TO 2016/17)

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Abstract

Introduction: Biathlon is a complex sport subjected to large performance variability. The analysis and extrapolation of the factors affecting prone or standing shooting and skiing world-class biathlon performances can therefore help improving the training programs according to the biathletes' specific needs. **Methods:** The analysis comprises data from IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games over eight years from season 2009/10 to 2016/17. The research includes sprint, individual, pursuit and mass start competitions for both elite men and women. Factors such as ranking variability, gender, age, type of event, altitude, head-to-head versus individual shooting and shooting progression and the overall best contemporary biathletes' performances have been investigated through data-crossing. **Results:** The ranking variability goes down to a ratio of 1.2 medals per biathlete in the male individual discipline. Gender shooting performances are very similar; however, women seem to mature earlier and reach the optimal performances later than men, not only for shooting performances but also skiing speed and ranking averages. Age plays an important role in all the performances; for example, 17 year old male biathletes have an average of proportional hit 23% inferior to 35 year olds. IBU Cup performances are lower than IBU World Cup ones from 3.6% to 6.0% in average. Performances can be deteriorated by altitude up to 2.8%. Male Top-30 head-to-head shootings are 2.2% lower than individual shootings. The overall shooting performances follow a slender but continuous improvement, in all competitions, ranking groups and genders; the shooting average amelioration between the 8 seasons is of 1.3%. **Discussion:** Biathletes' have specific performance trends according to gender and age, altitudes over 1400 m deteriorate both shooting and skiing performances and shooting performances degrade with head-to-head confrontation. These findings should be taken into account in the biathletes' training plans.

Titre en Français

Analyse des performances hommes et femmes du biathlon mondial (2009/10 - 2016/17)

Résumé

Introduction: Le biathlon est un sport complexe soumis à une grande variabilité de performance. L'analyse et l'extrapolation des facteurs qui influencent la précision de tir et les performances en ski des biathlètes de classe mondiale peuvent aider à améliorer les programmes d'entraînement en fonction des besoins spécifiques. **Méthodes:** L'analyse comprend les compétitions de l'IBU Cup, Coupe du Monde IBU, Championnats du Monde IBU et Jeux Olympiques d'Hiver des saisons 2009/10 à 2016/17. Les compétitions incorporées dans la recherche, pour hommes et femmes, sont: sprint, individuelle, poursuite et mass-start. Les éléments comme la variabilité des classements, le genre, l'âge, le type de compétition, la tir tête-à-tête contre l'individuel et la progression au tir et les performances des meilleurs biathlètes contemporains ont été investigués par le croisement des datas. **Résultats:** La variabilité du classement va jusqu'à un ratio de 1.2 médailles par biathlète pour la compétition individuelle masculine. Les performances de tir sont très similaires entre les genres; cependant, les femmes semblent mûrir plus tôt et atteindre les performances optimales plus tard que les hommes, non seulement pour les performances de tir, mais aussi pour la vitesse en ski et les classements moyens. L'âge joue un rôle important dans toutes les performances; par exemple, les hommes de 17 ans ont, en moyenne, une précision de tir de 23% inférieur aux biathlètes de 35 ans. Les performances de la IBU Cup sont de 3.6% à 6.0% inférieures à celles de la Coupe du Monde IBU. Les performances peuvent être détériorées par l'altitude jusqu'à 2.8%. Les performances de tir du Top-30 masculin sont 2.2% plus basses en tête à tête que en individuel. Les performances en tir suivent une faible mais constante amélioration saison après saison dans toutes les compétitions, niveaux et genres; l'amélioration moyenne du tir entre les 8 saisons est de 1.3%. **Discussion:** Le genre et l'âge des biathlètes ont des tendances spécifiques, les altitudes supérieures aux 1400 m abaissent les performances de tir et de ski et les performances de tir dégradent dans les compétitions en tête à tête. Ces résultats devraient être pris en compte dans la planification des programmes d'entraînement des biathlètes.

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1. Introduction

Biathlon is a winter sport that combines two different activities: cross-country skiing and 50 m rifle shooting. This sport is divided in several single and team competitions, which distinguish themselves by length, number of shootings series, amount of participants, types of penalties and gender. The four main individual races, that could be considered the most important ones and that count for the overall rankings are sprint, individual, pursuit and mass start. Sprint competitions are 10 km long for men and 7.5 km for women, individual are 20 km for men, 15 km for women, pursuit 12.5 km for men and 10 km for women and mass start 15 km for men and 12.5 km for women. Sprint comprises two shooting series, whereas the other three competitions include four series. All the shooting series are composed by 5 shootings and are homogeneously distributed through the length of the competitions. For every missed shot in sprint, pursuit and mass start, the athlete has to complete an additional loop of 150 m. For the individual races, every missed shot corresponds to a penalty of 1 minute added to the final time.

The mixing of cross-country skiing and rifle shooting, which require two disparate abilities, combined with a mutable environment, results in a great performance variability, making thus of biathlon one of the most inconstant and unpredictable sport.

Biathlon has been investigated in many directions in the last decades: Larue, Bard, Otis and Fleury (1989) showed how expert biathletes used different shooting strategies than expert rifle shooters, Laaksonen, Ainegren, and Lisspers, (2011) tested and proved the efficiency of a combined relaxation and specific shooting training regimen as refining the shooting performances, Luchsinger (2015) demonstrated that expert biathletes have a higher frontal theta activity during shooting compared to shooting novices, whereas Skattebo and Losnegard (2017) demonstrated the higher variability in biathlon's sprint performances, calculated the influence of altitude, climb gradient, wind and type of snow on the final time and determined the minimal performance improvement for a worthwhile enhancement. These studies only focus on specific features of biathlon and are applicable only to a smaller degree to the improvement of the performances of this sport.

The aim of the present study, compared to the previously listed, is a broader inquiry into the elite results of this sport; the larger investigation with the support of the existing findings aim to provide substantial evidence for practical applications on long-term training plans in addition to a better understanding of biathlon.

In order to have a data sample large enough to comprise significant amounts of performance observations for the multifactorial analysis, this thesis includes shooting and skiing performances from four types of individual competitions (sprint, individual, pursuit and mass start), for both men and women and from the two elite competition levels (IBU Cup and IBU World Cup). Finally, the last two Olympic cycles, or from season 2009/10 to 2016/17, are chosen to represent the contemporary condition and progression of this sport.

These performance observations are separated and analysed on several performance-related factors, such as biathletes' age, type of event, altitude of the competition and the head-to-head versus individual shooting. To better understand the general evolution of biathlon performances, these analyses are supplemented by a detailed examination of the evolution through the seasons of the different shooting performances. The case studies of the two overall best biathletes of season 2016/17, Laura Dahlmeier and Martin Fourcade, complete the research with an in-depth investigation.

Finally, the broad and multifactorial analyses undertaken by this thesis are necessary in order to better understand the specificities and the complexity of biathlon and to produce useful outcomes applicable to this sport.

2. Hypotheses

Hypothesis 1 – Ranking variability: According to Skattebo and Losnegard (2017), the high variability of race factors in biathlon's sprint competition, such as shooting performance, weather and snow conditions, seem to induce a larger ranking changeability compared to other sports. We tested the hypothesis that *the same variability is also found in the individual, pursuit and mass start competitions.*

Hypothesis 2a – Age and gender: The age difference between elite biathletes corresponds to their maturity; as it is the case for all type of tasks, the total number of hours of practice generally leads to better performances. We tested the hypothesis that *younger biathletes have less chance to have the same speed and shooting accuracy as the top ranking biathletes, and therefore less probability to rank in the top groups.*

Hypothesis 2b – Age and gender: Aging normally affects more the physical performance compared to the technical one. We tested the hypothesis that *aging results in the degradation of skiing speed and the maintenance of the shooting accuracy, for both men and women.*

Hypothesis 2c – Age and gender: Women, if compared to men of the same age, have a more precocious physical and psychological development. We tested the hypothesis that *women have a smaller disparity in the overall performance between the younger female biathletes and the top ranking ones compared to men.*

Hypothesis 3a – Type of event: We tested the hypothesis that *IBU Cup show lower skiing speed and shooting performance averages compared to IBU World Cup*.

Hypothesis 3b – Type of event: Due to the greater importance of the main championships (IBU World Championships and the Olympic Winter Games), the training plan of the biathletes is built in order to reach the top physical condition for these events. We tested the hypothesis that *the overall performances for the Championships are higher than both IBU Cup and IBU World Cup.*

Hypothesis 4 – Altitude: As the altitude of the competitions increases, the inspired oxygen pressure decreases. The hypoxic exposure results in an increase of exercise heart rate and ventilation and in a loss of coordination and balance and therefore might have an impact on the skiing and shooting performances. The IBU event and competition rules – point 3.3.2 – mention that "*The maximum altitude of any part of the course may not be higher than 1800 m above sea level, unless an exception is specifically authorized by the IBU EB in necessary circumstances*". There is a large range of altitudes (between 62 and 1750 m) that could lead to significant difference in performances. We tested the hypothesis that *both shooting and skiing performances were altered at higher altitudes (>1400 m) when compared to lower ones (<700 m).*

Hypothesis 5 – Shooting confrontation type: The psychological pressure of specific shooting environments could possibly influence the shooting performances. For sprint and individual competitions biathletes start individually with regular intervals between each other. At the finish line, the time is calculated from the departure and the arrival of the same athlete. For pursuit, biathletes start with a handicap calculated on the arrival time of a previous sprint race, whereas for mass start biathletes start simultaneously. In these last two races, the ranking is calculated on the exact order of arrival. The head-to-head between the biathletes in these two competitions could raise the psychological pressure on the shooting ranges, where overtaking or being overtaken by an opponent could be determined by every single shot. We tested the hypothesis that *the higher psychological pressure on head-to-*

head shootings plays a degrading role in pursuit and mass start shooting performances, for both male and female biathletes.

Hypothesis 6a – Shooting performances: Shooting performances are influenced and improved over time by more specific trainings, improved techniques and more precise rifles. We tested the hypothesis that *shooting performances improve over the eight-year period for men and women*

Hypothesis 6b – Shooting performances: As the accuracy gap gets closer to 100% the average ameliorations follow a logarithmic trend. We tested the hypothesis that *Top-30 and Top-10 biathletes would improve more than Top-3 biathletes*.

Hypothesis 6c – Shooting performances: Standing shooting is being realized in a less stable position if compared to prone. We tested the hypothesis that *standing shooting performances are lower than prone shooting ones*

Hypothesis 7a – Case studies: At the end of season 2016/17, Laura Dahlmeier won her first IBU World Cup big crystal globe, as the overall best female biathlete, while Martin Fourcade has been awarded the same prize six seasons in a row, from 2011/12 to 2016/17, as the overall best male biathlete. During season 2016/17, Fourcade won four small crystal globes and Dahlmeier two. We tested the hypothesis that *Fourcade has a bigger gap with the Top-5 biathletes than his female counterpart.*

Hypothesis 7b – Case studies: Dahlmeier, born in 1993, is five years younger than Fourcade. We tested the hypothesis that *Dahlmeier has a greater skiing and shooting performance progression in the last seasons compared to Fourcade*.

3. Methods

Official race times and course information from IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games were extracted from the IBU website (www.biathlonworld.com) from 2009/10 to 2016/17 for sprint, individual, pursuit and mass start. As all data existed in the public domain, no written informed consent was requested. Microsoft Excel files have been used for the treatment of data. Since Skattebo and Losnegard (2017) showed that the shooting times were statistically insignificant for the final results of sprint, we hence considered this finding valid for the other three races, for both men and women. Therefore the present study focused on skiing times (without penalties – see below – but incorporating the shooting time) and shooting accuracies.

Race rankings of pursuit have been recalculated on the effective skiing times, by subtracting the handicap times from the final ones, in order to have real-time rankings and a better relation between rankings, skiing speed and shooting accuracy.

Skiing speeds have been calculated with the data available. For sprint, pursuit and mass start, 23 seconds for men and 25 seconds for women were subtracted for every missed shot as equivalents to the average times for a single penalty loop (Skattebo and Losnegard, 2017). For individual race, 1 minute was subtracted for every missed shot. Finally, these new times divided the lengths of the races (rounded up to the standards) to find the skiing speed for each athlete.

Proportional hits, for prone and standing shooting, were determined for every biathlete by dividing the number of targets by the number of hits.

Final times considered the times formerly calculated for the race rankings with the subtraction of pursuit's handicaps.

Data are reported as mean and standard deviation (SD); these are determined by the average of the means of the four different competitions. The analyses were completed using SigmaStat 3.5 software (Systat Software, San Jose, CA). For comparisons between male and female performances, altitudes, ages and head-to-head versus individual shootings, a non-parametric one-way ANOVA on ranks was used since the distribution of the data was not normal. Statistical significance was set a priori at $p\text{-value} < 0.05$.

The specific methods applied for each table and figure are described in the following paragraphs.

Table 1, which portrays the total number of races, its annual average and standard deviation, considered all the data used for the paper.

Tables 2 and 3, which portray the number of male and female biathletes in relation with the ranking groups and seasons, were determined with the full names of the biathletes present in the database. However, disqualifications were not removed from the results and eventual changes of name were not taken into consideration as single units.

The ages in Figure 1, displaying the evolutions of men and women in skiing speed, shooting accuracy and ranking possibility through their ages, were calculated for every race and for all biathletes by using the event's date and the dates of birth. For the six figures, only the ages 17 to 38 included were taken into account in order to have a representative amount of results for every age. Three types of p-values (with $p\text{-value} < 0.05$) were determined for these graphs: the first one portrays the significant differences with the youngest age, while the second and the third show the significant differences with the optimal age towards the youngest and the oldest age respectively.

Unfinished races or disqualifications were not taken into account in the results. Skiing speed graphs were created with the averages of the single ages. Proportional hit graphs considered the prone and standing shooting averages for the curves, and the total shooting averages for the p-values. Ranking possibility line charts display the likelihood of finishing in the Top-3, Top-10 and Top-30 for every age; for Top-30, mass start results are not taken into account since it would have involved all the contestants and not a specific ranking group. Ranking possibility p-values considered instead the average rankings for every age.

In Figure 2, which portrays the difference between the types of event on skiing speed, shooting accuracy and final time, IBU World Championships and Olympic Winter Games are considered as “Championships”. For every type of performance, the averages of the single races’ Top-30 were considered for the drawing of the histogram charts. The p-values express the difference between the three types of event.

Figure 3 shows the Top-30’s average performances at three different altitude ranges. The races where divided in the three groups with the official elevations found on the IBU website. The two limits, 700 m and 1400 m, were used in order to have enough data in the three categories for a substantial statistical analysis. The climbing gradient of the slopes and the consequent change of altitude at the shooting ranges were not taken into consideration in the analysis since they are insignificant in the total altitude. For every type of performance, the averages of the altitude groups were taken into account for the graphs. The p-values express the difference between the performances of the three altitude groups.

Figures 4 and 5 portray the type of shooting environment, individual or group (head-to-head) shooting, for men and women respectively. Sprint and individual competitions were categorized as “individual shooting” and pursuit and mass start as “group shooting”. The averages of the overall shootings for the two groups, for the single races’ Top-3, Top-10 and Top-30, were used for the histograms. For each ranking group, the p-values express the difference between the performances of the two shooting environments.

Figures 6 and 7 show the averages and standard deviations of Top-3, Top-10 and Top-30 shooting evolution from season 2009/10 to 2016/17 in the four competitions and overall, for men and women respectively. The p-values display the difference between the first and the last of the eight seasons only, without hence considering the six seasons among them. To better display the evolutions, a second-degree polynomial has been chosen as the best fitting curve for the results.

Table 4 and Figures 8 to 10 compare Laura Dahlmeier and Martin Fourcade’s results and performances. These two biathletes won 2016/17’s big crystal globes as the overall best and were consequently chosen for this in-depth analysis. Table 4 portrays the total of single races and IBU World Cup’s small crystal globes won every season and the IBU World Cup overall final ranking for the seasons 2008-2009 to 2016/17. Figure 8 displays the performance averages of these two biathletes through the seasons 2009/10 to 2016/17. The p-values were calculated on the singular trends, year by year, but also on the shooting difference between the two biathletes in the same season and at the same age. The identical procedure was adopted for Figure 9. Figure 10 compares Fourcade and Dahlmeier’s 2016/17 performances to the other four Top-5 biathletes of the overall IBU World Cup rankings, according to gender, in order to better understand the intra-gender degree of superiority of these two athletes. The differences were determined by comparing Dahlmeier and Fourcade’s averages to the means of the other Top-5, used as baselines. The Top-5 were chosen for these comparisons in order to obtain the finest performances possible as well as pools large enough to adjust the individual features.

4. Results

Table 1 shows that the total amount of competitions from season 2009/10 to 2016/17 is 667: 334 for men and 333 for women. If we consider all the athletes competing in the 667 races, we obtain a total amount of 43’331 performance observations. The annual average of 42 races is the same for men and women. Sprint is the competition with more races, with an average of 20 races per year and a total of 158 races for men and women. The less frequent race is mass start, with an annual average of only 5 competitions, 4 in the IBU World Cup and 1 in the Championships. Since the total number of participants is limited to 30, this makes mass start also the race with the lowest amount of performance observations; i.e., 5.4% of the total amount. The only difference in the amount of competitions between the genders is the total of pursuit races, 89 for men and 88 for women, due to the terrible weather conditions that made it impossible for Altenberg women’s pursuit in 2010 to take place.

Tables 2 and 3, which portray the number of male and female biathletes in relation with the ranking groups and seasons, show that the total number of biathletes that took part in the 667 competitions is 744, 383 men and 361 women. Men’s annual average is 239 biathletes, with a variation of 22, while for women’s is 205, with a variation of 15. Women’s group has been therefore slightly less modified than men’s in the eight seasons taken into consideration. The amount of biathletes occupying the top ranking groups for the sprint events, as highlighted by Skattebo and Losnegard (2017) for the sprint competition, is highly variable. In fact, for an average of 42 competitions per year per gender, and therefore 126 podium places, we have a mean of 50 men and 47 women that have been awarded with at least one medal. Considering this, and as already reported (Skattebo and Losnegard, 2017), the performance variability in biathlon is very high. For both men and women and the three ranking groups, the most variable competition is individual, followed by pursuit, mass start and finally sprint. An annual average of 14 men and 15 women were awarded with one or more medals within the 18 medals (ratio of 1.2 medals per biathlete) available per year and per gender in the individual race. In contrast, an average of 32 men and 32 women won the 60 medals (ratio of 1.9 medals per biathlete) available per year in the sprint races per gender. The only remarkable variation between the amounts of biathletes is the total number of participants in the season 2016/17 compared to the previous ones; for instance, in the season 2012/13 there were 265 different men biathletes, while in the 2016/17 season only 197. Women follow the same trend but in a smaller degree.

Figure 1, which displays the evolutions of men and women in skiing speed, shooting accuracy and ranking possibility through the biathletes' ages, shows significant differences. Skiing speed comparison with the youngest age shows that men after 20 years of age and women after 19 years of age have performances significantly superior. The progression on shooting precision in comparison to the 17 year olds appears at the age of 20 for men but only at the age of 34 for women; this difference is due to a smaller gap between young female biathletes and top ranking ones in comparison with men, who have a significantly lower shooting precision at the youngest age. Inversely, ranking possibility's significant difference begins at the age of 20 for both men and women. The optimal ages in skiing speed are from 27 to 29 for men and 32 for women. The significant differences with these ages are at 22 years and younger for both men and women. Proportional hit's optimal ages are 35 for men and 34 for women, and the significant differences are at 21 years and younger for men and 24 years and younger for women. The peak performance ages for ranking possibility are 27 for men and 32 for women, while the significant differences are at 23 years and younger and 32 years and older for men and at 28 years and younger for women. For what concerns women's Top-3, Top-10 and Top-30 ranking possibility, the peaks are at 29, 34 and 32 years, respectively. Contrariwise, men's ranking groups have all a peak performance at the age of 27.

Figure 2, which portrays the difference between the types of event on skiing speed, shooting accuracy and final time, shows statistical differences in the performances between the three types of event. Men's proportional hit between IBU World Cup and Championships does not show any significant difference. However, for all the other comparisons, for both men and women, the differences are significant; IBU Cup has always the lowest performances and the Championships the highest. The changes between IBU Cup and IBU World Cup for skiing speed are 4.4% for men and 6.0% for women, for proportional hit 5.0% for men and 3.6% for women and for the final times 17.4% for men and 18.2% for women. Skiing speed variations between IBU World Cup and Championships are 3.3% for men and 3.8% for women, for proportional hit 1.9% for women and for final times 3.7% for men and 3.8% for women.

Figure 3, which shows the Top-30's average performances at three different altitude ranges, displays several significant differences between the altitude levels. Men's skiing speed does not seem affected by altitude, whereas women's skiing performance is altered: between <700 m and 700-1400 m there is degradation with a decrease of 2.2%, between <700 m and >1400 m a degradation of 0.9% and between 700-1400 m and >1400 m the average performance decreases by 1.3%. Women's proportional hit between <700 m and 700-1400 m is the only comparison that does not show significant differences in the shooting performances; all the others decrease as the altitude increases. Between <700 m and 700-1400 m, the proportional hit varies by 1.4% for men, between 700-1400 m and >1400 m, by 1.4% for men and 2.2% for women and between <700 m and >1400 m by 2.8% for men and 2.5% for women. Likewise, the significant results for the final times show significant degradations with the increase of the altitude: between <700 m and 700-1400 m, women's performances decrease by 1.9%, between 700-1400 m and >1400 m, by 1.3% for men and between <700 m and >1400 m by 1.3% for women.

The type of shooting environment displayed in Figures 4 and 5 portrays deteriorations in the head-to-head shooting performances in comparison to the individual shooting ones. However, the degradations are significant only for the Top-30; in this ranking category, the group shooting performances deteriorate by 2.2% for men and by 2.0% for women.

Figures 6 and 7 show improvements of the shooting performances for men and women in almost all the competitions, types of shooting and ranking categories. The only significant deterioration occurs in the individual competition for women's Top-10 and Top-30's total shooting, where the degradation is 1.8% and 3.5% respectively. However, for this specific shooting the trend does not differ from the normal tendency, as the second-degree polynomial displays an overall improvement. Between the first and the last of the eight seasons, men's overall prone shooting shows an improvement of 2.1% for the Top-3 and 1.0% for the Top-30, for overall standing shooting 1.8% for both the Top-10 and Top-30 and for the overall total shooting 1.5% for Top-10 and 1.1% for Top-30. Men's most remarkable change occurs in mass start standing shooting's Top-30, with a change of 4.5% in the eight years. Women's overall prone shooting changes by 3.6% for the Top-3 and 1.9% for both the Top-10 and Top-30. Despite the fact that the overall standing shootings do not display any significant change, the trends visually improve through the seasons. The overall total shooting improves by 2.7% for Top-3 and 1.2% for Top-10. The most remarkable changes in women's shooting performances occur in sprint prone shooting Top-3 and Top-10 with improvements of 6.0% and 4.3% respectively. Standing shooting performances are generally lower than prone shooting's. Only on two occasions standing averages surpass prone averages: 2009/10 sprint women's Top-3 has and average of 90.5% in prone shooting and 92.6% in standing shooting. Also, 2016/17 mass start women's Top-3 has an average of 94.0% in prone shooting and 96.0% in standing shooting. However, these differences are statistically insignificant.

Table 4 displays how Fourcade has been the best biathlete for longer than Dahlmeier. Every season, Fourcade won more races and small crystal globes compared to his female equivalent, even in season 2016/17 when both won the big crystal globe. Considering that Dahlmeier is 5 years younger than her opponent, the same-age perspective should be considered: both of them reached the top of the overall ranking at the same age, but Dahlmeier won more races during seasons 2015/16 and 2016/17 compared to Fourcade at the same age. Fourcade won his first small crystal globe two years earlier than his opponent and was ranked better than her the two years preceding the reaching of the top of the overall ranking. Figure 8 shows a continuous progression for both biathletes in skiing speed and proportional hit. Fourcade improved significantly in skiing speed between seasons 2010/11 and season

2012/13, and also from season 2014/15 and 2015/16, while Dahlmeier improved with a degree of 95% between seasons 2013/14 and 2014/15 and a degree of 99.9% between seasons 2013/14 and 2016/17. Even observing Fourcade's progression at Dahlmeier's age, she seems to have a sharper improvement in the skiing speed compared to her male equivalent. The proportional hit graph shows how Fourcade significantly improved from season 2011/12 to 2012/13. Moreover, the line chart shows how Dahlmeier's total shooting precision surpasses Fourcade's from season 2013/14 to 2016/17. However, this difference is not statistically significant. If the 5 years of age difference are taken into account, Dahlmeier's 2016/17 shooting performances compared to Fourcade's 2011/12 are significantly higher. Figure 9 shows how the previous results, such as Fourcade's total shooting statistical progression, and the total shooting difference between the biathletes, as well as the same age statistical difference, find their roots in the standing shooting. The charts show how the difference in prone shooting is practically inexistent between the two biathletes, while Dahlmeier's standing proportional hit is higher than Fourcade's. Finally, Figure 10 displays how both Fourcade and Dahlmeier overpowered the other 2016/17 overall Top-5 biathletes in all types of performances. Skiing speed difference is higher for Fourcade, whereas shooting accuracy is higher for Dahlmeier, while the final times seem equivalent between the two. However, the only significant difference is Dahlmeier's shooting accuracy, as it stands as 6.4% more precise in the total shooting performances in comparison with the other Top-5 women.

5. Discussion

The most remarkable outcome of Table 1 is the equality between the amount of men and women's competitions. Also, the amount of participants displayed in Table 2 and 3 does not show a substantial difference between the genders. Moreover, the annual money prize between men and women appears also to be equal (Real Biathlon). Considering that in many other sports men have the lead on women in the number of competitions and of professional athletes and the biggest part of money prizes, biathlon could be considered a sport that promotes gender equality. In fact, only the length of the races seems to separate women from men.

Tables 2 and 3 not only confirm the hypothesis of the variability made by Skattebo and Losnegard (2017), but show a greater inconsistency in the results of individual, pursuit and mass start races. In fact, it seems that as the length of the race increases and the number of shooting doubles, the results' variability rises to a greater degree, for both men and women. Consequently, if a biathlete normally classed ~15th could win a sprint race according to Skattebo and Losnegard (2017), biathletes normally classed even lower than that could possibly win an individual, pursuit or mass start race.

The progression on skiing speed and proportional hit between 17 and 24 years is sharper and longer for men than for women; this confirms the hypothesis that women mature sooner than men. However, the optimal ages for the skiing speed, proportional hit and ranking possibility come later for women than for men; this finding shows also how female biathletes are more constant in their performances' progression. Shooting accuracy seems affected less than skiing speed by aging. In fact, the shooting accuracies after the age of 22 are practically stable for both genders;

the only remarkable differences are the higher performance in women's standing shooting after the age of 29 and the consequent smaller gap between prone and standing proportional hit for women in comparison with men. Women's skiing speed consistency seems to be the major factor affecting the ranking possibility; in fact women's ranking optimal age comes five years after men's, mirroring skiing speed's trend. However, at the age of 38, women do not have biathletes in the Top-30 while men still do; this could be explained by many reasons, such as women's pregnancies, men's longer history in biathlon and exceptional senior male biathletes such as Ole Einar Bjørndalen and Christoph Summan.

The hypothesis advanced on the type of events is also confirmed, as performances during Championships are the highest and those at the IBU Cup the lowest between the groups. Interestingly, women's amelioration at the Championships compared to IBU World Cup is slightly bigger than men's; this could be explained by a higher psychological strength under the pressure of important events.

As advanced by the hypothesis, altitude influences the overall performances. However, if skiing speed seems less affected compared to proportional hit, it is due to the higher number of factors influencing it, such as snow and weather conditions and climbing degree.

Figures 4 and 5 confirm that shooting head-to-head has a negative impact on the psychological side of the biathletes. Top-3 and Top-10 are probably less affected than Top-30 because of their experience and specific trainings. Women are slightly less affected than men, highlighting once more women's greater psychological strength under pressure, previously identified in Figure 2's analysis.

Shooting accuracy progresses throughout the seasons on all types of shooting, for the three ranking groups and for both genders, confirming thus the hypothesis formed beforehand. We also assumed that the Top-30 would have progressed more than the Top-10 and Top-3 as the gap toward perfection closed down; however, since the improvements are too small on the overall scale, this supposition cannot be confirmed.

As displayed in Table 4, the comparison between the two 2016/17 overall World Cup champions shows Fourcade's lead on the number of season-related victories and on the skiing speed compared to the Top-5. However, within the season-related results Dahlmeier overpowers Fourcade on the standing shooting performances and has the only significant difference in the Top-5 comparison. Finally, if the two biathletes are compared with their age-related performances, Dahlmeier has similar or better rankings and significant shooting differences compared to Fourcade. Taking into account that Dahlmeier's 2016/17 big crystal globe is her first one and that it is obtained at the same age as Fourcade, we could conclude by saying that if she follows the same path as her male equivalent, she could remain the queen of this sport for many years.

6. Practical Applications

Considering biathlon as a sport where equality between genders can be found in almost every aspect, and the fact that gender equality is one of the major contemporary subjects, biathlon federations could find more support by using this feature to get further public attention and, as a consequence, more active members and sponsors.

Coaches could use individual's higher variability as a mean to train less consistent or young biathletes, in order to make them gain in experience and eventually approach the podium.

Concerning age progression and peak ages, coaches should consider the findings and the differences highlighted between the genders and build the long-term training-plans accordingly.

As displayed in Figure 2 and described by Skattebo and Losnegard (2017), Championship's performances are significantly higher than IBU World Cup's. The trainings should therefore be planned to reach the optimal form at the Championships, or the experience would be the only outcome gained from it.

Coaches and federations should consider organizing training camps in hypoxia to improve their athletes' adaptation to altitude aside from VO_{2max} and overall endurance. More importantly, if the Championships take place in altitude, a perfect planning of hypoxic trainings is necessary to reach the peak form at these events.

Since head-to-head shootings show significant degradations compared to the individual ones, exercising this aspect by organizing group shooting training sessions in a competitive environment could lead to important ameliorations in pursuit and mass start overall performances.

Finally, Dahlmeier and Fourcade's coaches could take into consideration the findings of this research to keep their athletes at the top for the longest possible time.

7. Conclusion

The outcomes of this paper confirm the complexity of biathlon, agreeing with Skattebo and Losnegard's (2017) findings. Moreover, we have seen how age and gender have different and specific trends on the skiing speed and shooting accuracies, how altitude and head-to-head competitions affect the various types of performances and how this sport is continually evolving.

In order to understand if the practical applications presented in this paper are correct, it would be interesting to put them into practice. For instance, for further analyses it would be interesting to investigate if the advertising of a sport as promoter of gender equality has positive impacts on that particular sport, or also, to study the various methods to increase the effects of hypoxic trainings on the performances that take place above the 1400 m.

Even though the number of studies about biathlon is constantly increasing, this sport is contingent on too many factors, most of them uneasy or impossible to extrapolate. This leads us to the conclusion that biathlon single performances are, and will thus remain, far from justly predictable.

8. Afterword

To optimize this research, or future studies, several inaccuracies should be taken into account.

To obtain more remarkable differences between the three ranking groups and more significant results, the analysis should have been led differently. In fact, Top-3, Top-10 and Top-30 averages should not have been calculated considering IBU Cup and IBU World Cup on a same level; as portrayed in Figure 2, the performance's difference between the events is highly significant. IBU Cup and IBU World Cup differences should have been therefore included in the different analyses.

Skiing speeds were only representative of the real speeds as including the shooting times. Moreover, the analysis did not consider that sprint competition has half the number of shooting series compared with the other three competitions. However, as the average speeds are always calculated with the mean of the four competitions, the results are truthful representations of the real speeds. For future analysis I would advise to find a system to extrapolate the real speeds.

The proportional hits in the various figures were calculated with the mean of the single races. This computation did not take into consideration that in the sprint competition there are two times less shootings than in the other competitions. Sprint competition performances are therefore over represented and this mistake should be avoided in future analyses.

Finally, since Dahlmeier overpowers Fourcade in standing shooting performances and not in prone shooting, it would have been interesting to compare her two shootings with the overall Top-5, and see to which degree she overpowers her opponents in the two types of shooting.

9. References

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Table 1: Number of competitions

COMPETITIONS

		Number of races	Annual Mean ± SD
Men	Sprint	158	20 ± 1
	Individual	48	6 ± 1
	Pursuit	89	11 ± 1
	Mass Start	39	5 ± 0
	Total	**334**	42 ± 1
Women	Sprint	158	20 ± 1
	Individual	48	6 ± 1
	Pursuit	88	11 ± 1
	Mass Start	39	5 ± 0
	Total	**333**	42 ± 1
All	Total	**667**	42 ± 1

SD, standard deviation

Total number, average and standard deviation of the competitions taken into account by the study, for men, women and overall. The data involve four elite competitions: sprint, individual, pursuit and mass start, from season 2009/10 to 2016/17 and from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

Table 2: Number of male biathletes

		MEN				
Season	**Ranking**	**SP**	**IND**	**PU**	**MS**	**All**
09-10						
	Top-3	36	15	28	13	57
	Top-10	79	40	62	25	94
	Top-30	145	98	144	41	170
	All	256	227	178	41	256
10-11						
	Top-3	36	19	21	10	53
	Top-10	80	49	58	26	104
	Top-30	159	113	134	54	187
	All	248	240	164	54	249
11-12						
	Top-3	29	17	22	9	46
	Top-10	75	46	62	24	100
	Top-30	140	112	126	49	163
	All	247	235	166	49	248
12-13						
	Top-3	32	14	24	11	47
	Top-10	84	44	57	26	99
	Top-30	131	108	118	48	155
	All	263	243	175	48	265
13-14						
	Top-3	34	13	28	9	53
	Top-10	77	39	71	24	100
	Top-30	148	88	129	46	166
	All	248	220	178	50	249
14-15						
	Top-3	32	12	23	10	43
	Top-10	67	34	51	25	82
	Top-30	132	86	107	50	145
	All	226	207	143	50	228
15-16						
	Top-3	29	12	21	12	48
	Top-10	76	36	55	28	90
	Top-30	131	84	114	49	146
	All	218	191	157	50	219
16-17						
	Top-3	27	15	26	9	49
	Top-10	73	34	68	26	86
	Top-30	122	85	116	48	142
	All	195	182	154	48	197
All						
	Top-3	116	69	89	35	140
	Top-10	185	132	158	68	207
	Top-30	281	238	272	111	313
	All	383	379	319	111	**383**
All		**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
	Top-3	32 ± 3	15 ± 2	24 ± 3	10 ± 2	50 ± 5
	Top-10	76 ± 5	40 ± 6	61 ± 7	26 ± 1	94 ± 8
	Top-30	139 ± 12	97 ± 13	124 ± 12	48 ± 4	159 ± 15
	All	238 ± 23	218 ± 23	164 ± 13	49 ± 4	239 ± 22

SP, sprint. IND, individual. PU, pursuit. MS, mass start. SD, standard deviation.

Number of male biathletes finishing in the Top-3, Top-10 and Top-30 in one of the four competitions and the total number of biathletes participating, separated by type of competition and by season and grouped by competition and by season. The bottom list displays the annual average and its standard deviation. The data comprise elite athletes and four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

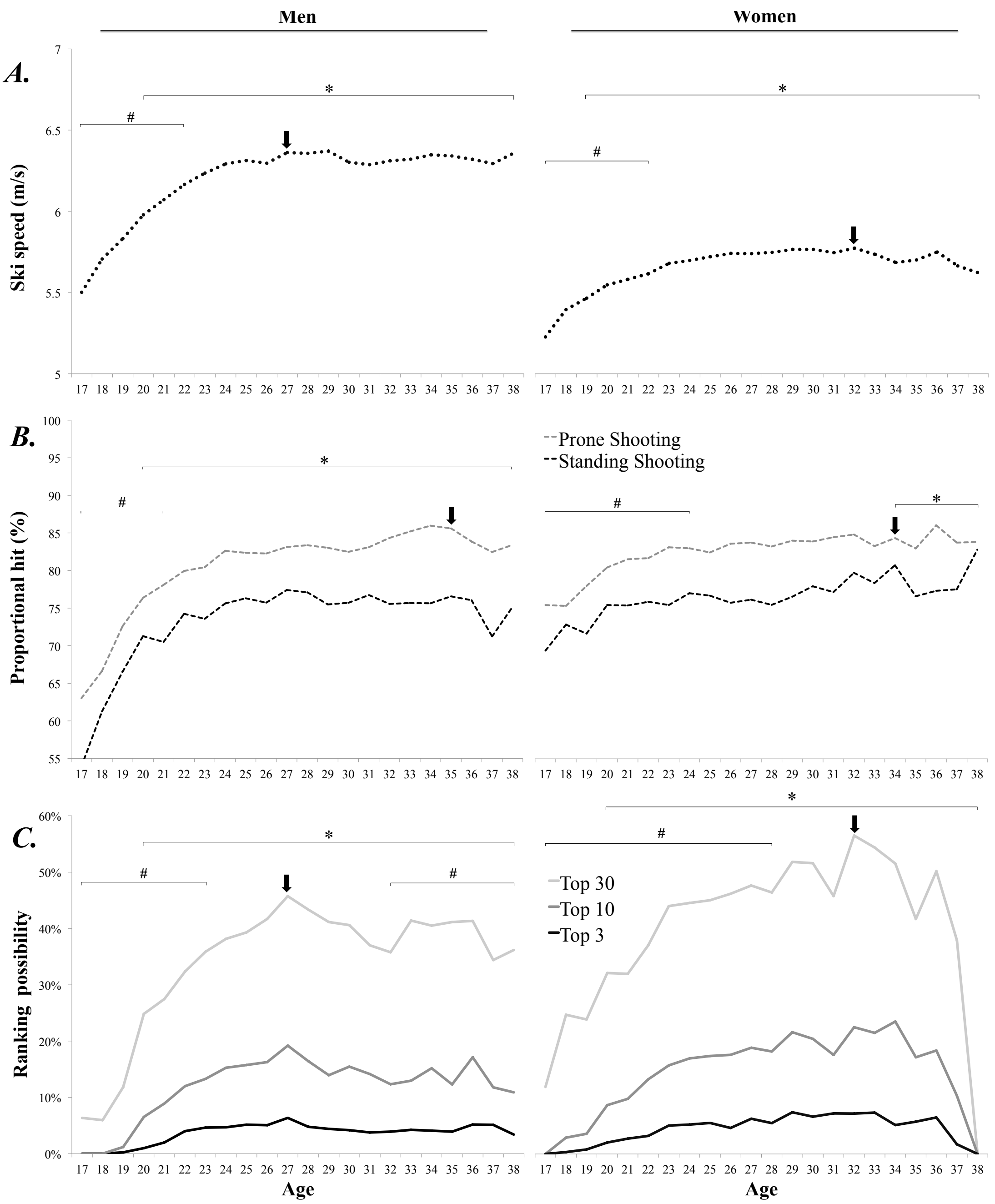
Table 3: Number of female biathletes

WOMEN						
Season	**Ranking**	**SP**	**IND**	**PU**	**MS**	**All**
09-10						
	Top-3	33	14	25	9	43
	Top-10	76	41	55	19	86
	Top-30	148	92	119	44	169
	All	217	178	162	44	217
10-11						
	Top-3	26	18	22	9	41
	Top-10	72	47	52	21	87
	Top-30	149	106	120	48	168
	All	206	183	159	48	207
11-12						
	Top-3	27	16	19	8	43
	Top-10	75	45	48	21	87
	Top-30	135	103	116	49	148
	All	210	196	155	49	210
12-13						
	Top-3	26	12	23	9	42
	Top-10	72	40	55	24	90
	Top-30	141	102	123	46	159
	All	219	194	169	46	219
13-14						
	Top-3	41	13	29	10	58
	Top-10	90	36	65	24	108
	Top-30	157	94	133	49	179
	All	223	194	175	50	223
14-15						
	Top-3	34	12	20	12	51
	Top-10	81	36	51	20	94
	Top-30	138	93	110	53	150
	All	192	172	149	53	192
15-16						
	Top-3	37	12	23	8	47
	Top-10	72	34	57	25	89
	Top-30	141	84	118	53	149
	All	191	171	155	53	191
16-17						
	Top-3	33	13	25	8	48
	Top-10	83	41	63	27	99
	Top-30	133	92	130	48	150
	All	181	167	155	48	182
All						
	Top-3	119	68	99	34	154
	Top-10	228	149	170	74	246
	Top-30	323	263	287	138	332
	All	361	354	335	138	**361**
All		**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
	Top-3	32 ± 5	14 ± 2	23 ± 3	9 ± 1	47 ± 6
	Top-10	78 ± 7	40 ± 5	56 ± 6	23 ± 3	93 ± 8
	Top-30	143 ± 8	96 ± 7	121 ± 7	49 ± 3	159 ± 12
	All	205 ± 15	182 ± 12	160 ± 9	49 ± 3	205 ± 15

SP, sprint. IND, individual. PU, pursuit. MS, mass start. SD, standard deviation.

Number of female biathletes finishing in the Top-3, Top-10 and Top-30 in one of the four competitions and the total number of biathletes participating, separated by type of competition and by season and grouped by competition and by season. The bottom list displays the annual average and its standard deviation. The data comprise elite athletes and four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

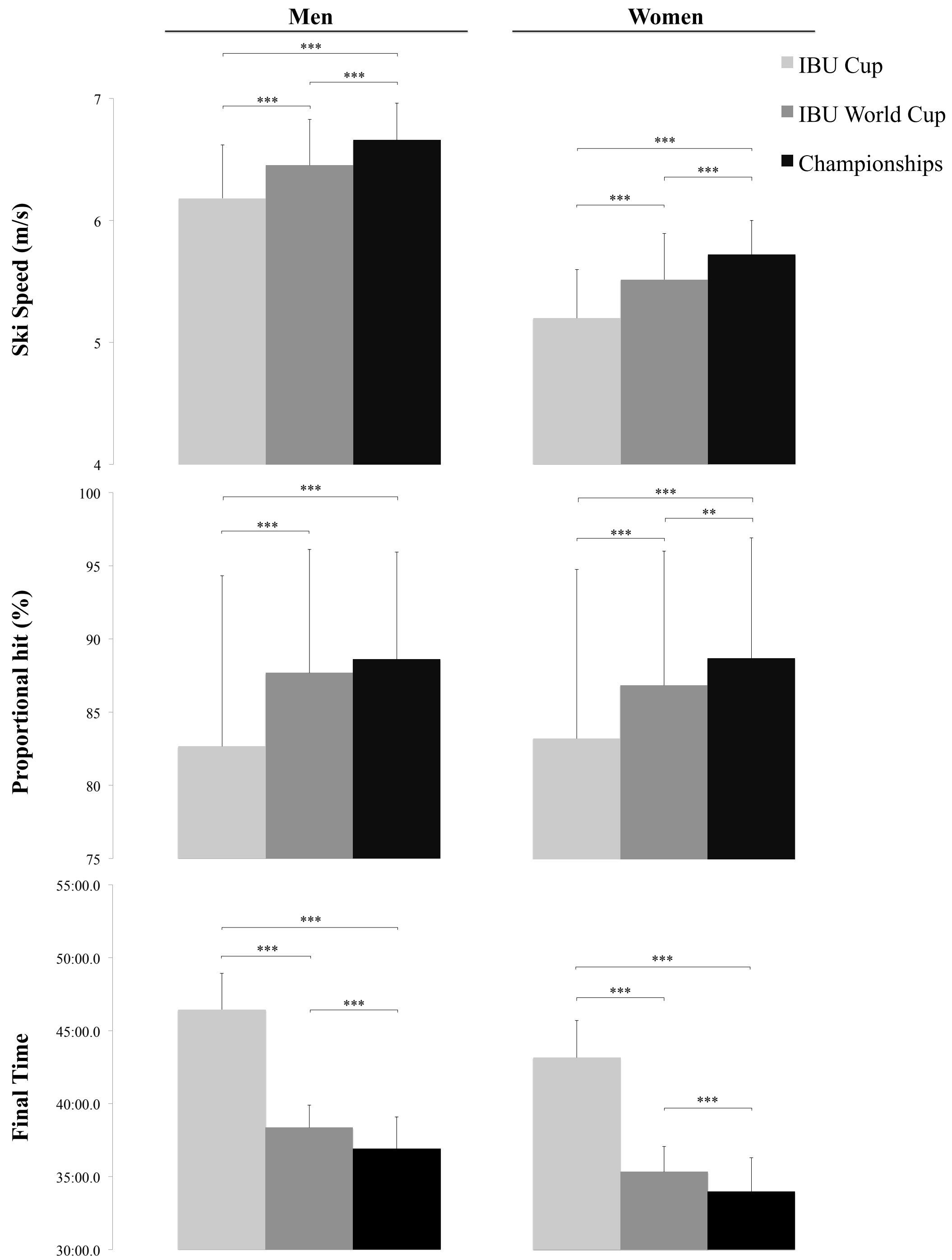
Figure 1: Effect of age on biathletes' performance



For difference with youngest age: *, $p < 0.05$
For differences with optimal age: #, $p < 0.05$
Optimal age: ➔

Average of skiing speed, proportional hit and ranking possibility of all elite biathletes, men and women, in relation to their age.
B: *Proportional hit: separated in the two different shooting positions.*
C: *Ranking possibility: likelihood of finishing in Top-3, Top-10 and Top-30 at each age; for Top-30, mass start results are not taken into account.*
The data are comprised of four competitions: sprint, individual, mass start and pursuit, are from season 2009/10 to 2016/17 and are from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

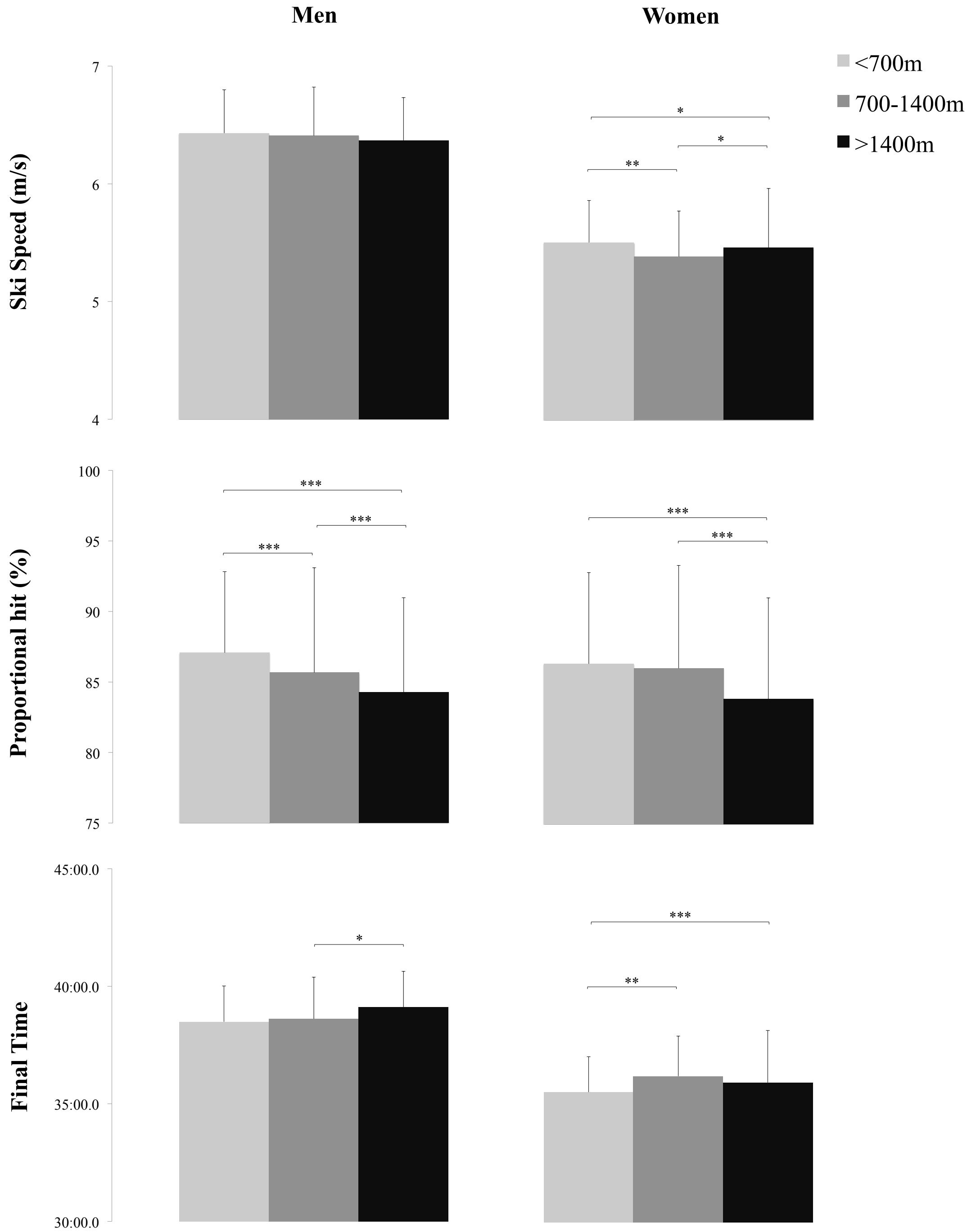
Figure 2: Effect of the type of event on biathletes' performance



**, p < 0.01; ***, p < 0.001

Average and standard deviation of skiing speed, proportional hit and final time of elite men and women in relation to the type of event. Championships group includes World Championships and Olympic Winter Games. The data comprise the values of each single race's Top-30 and are the average of the overall results of four competitions: sprint, individual, mass start and pursuit, and are from season 2009/10 to 2016/17.

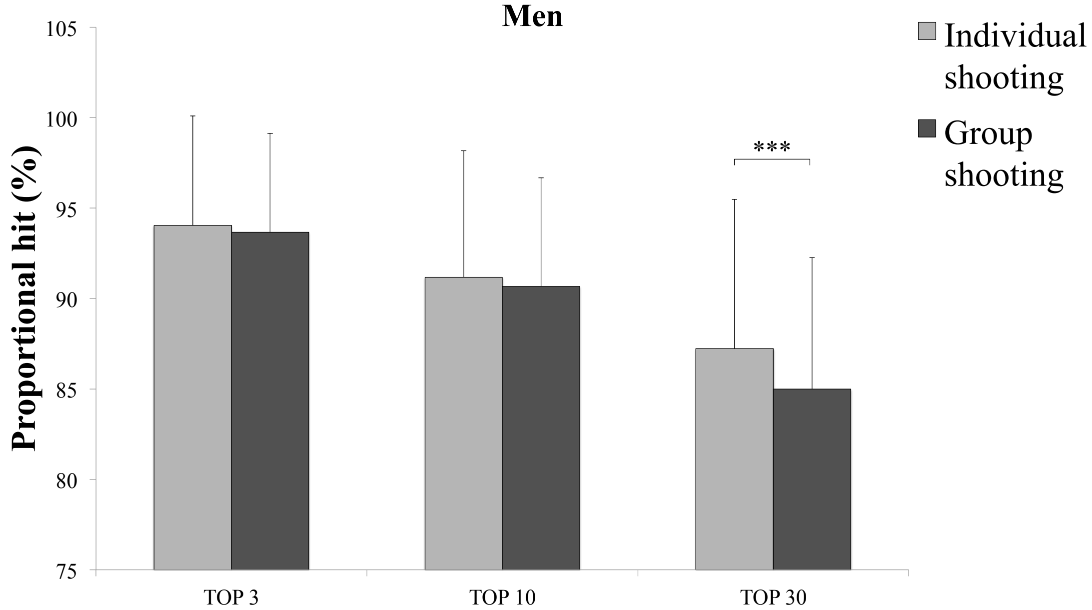
Figure 3: Effect of the altitude on biathletes' performance



*, p < 0.05; **, p < 0.01; ***, p < 0.001

Average and standard deviation of skiing speed, proportional hit and final time of elite men and women in relation to the altitude of the competition. The data comprise the values of each single race's Top-30 and are the average of the overall results of four competitions: sprint, individual, mass start and pursuit. The data are from season 2009/10 to 2016/17 and from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

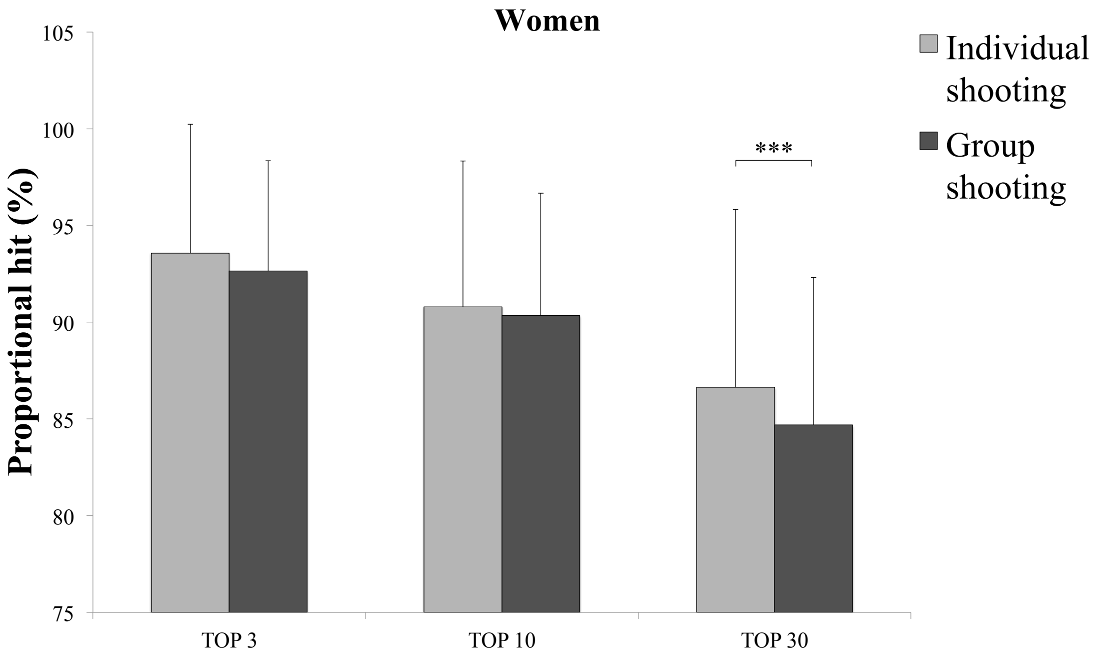
Figure 4: Male biathletes' individual and head-to-head shooting performances



***, p < 0.001

Average and standard deviation of the proportional hit of elite men shooting performances, for each single race's Top-3, Top-10 and Top-30. The competitions are categorized by type of shooting conditions: individual (for sprint and individual competitions) and group (for pursuit and mass start competitions). The data are from season 2009/10 to 2016/17 and from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

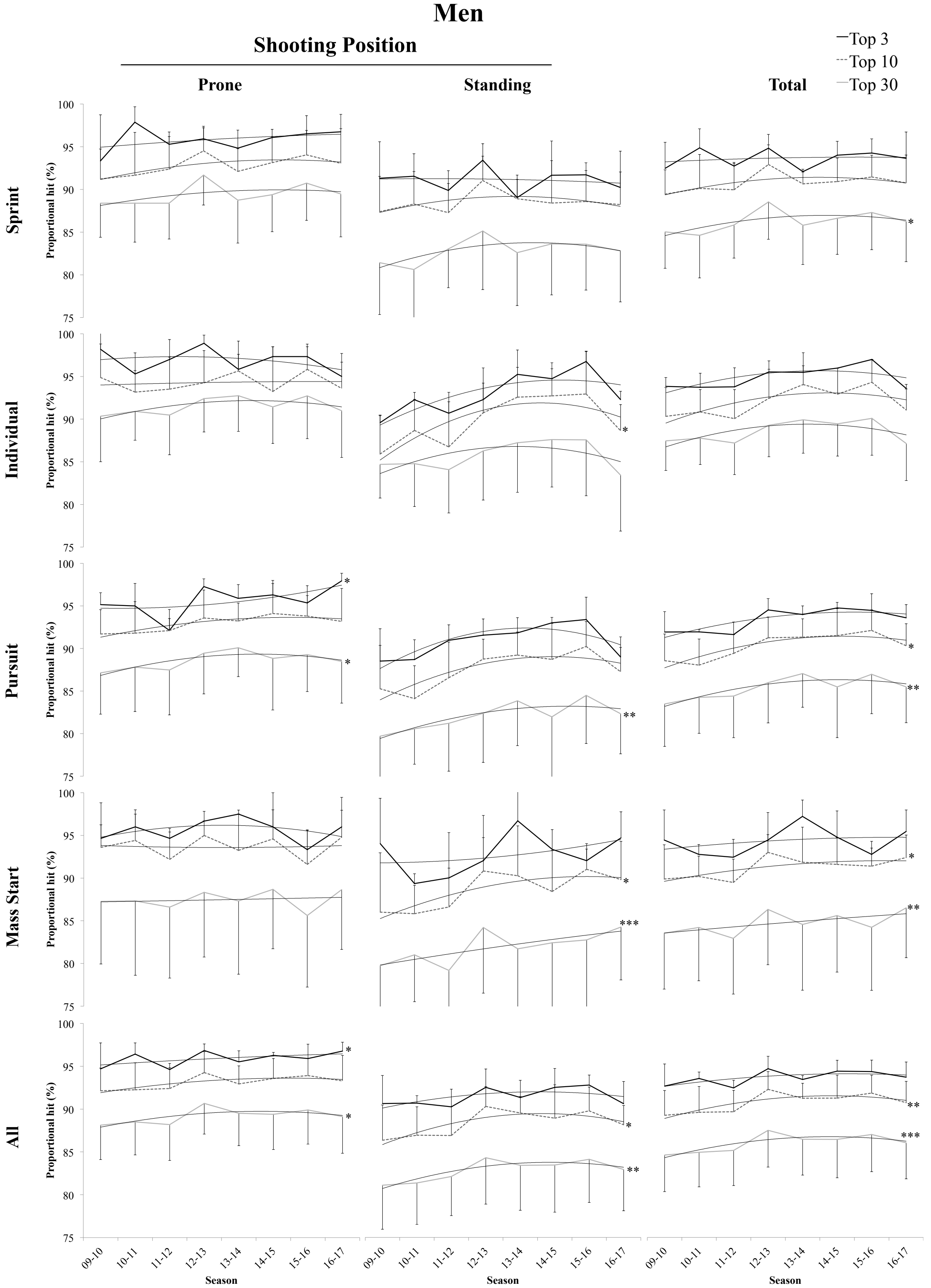
Figure 5: Female biathletes' individual and head-to-head shooting performances



***, $p < 0.001$

Average and standard deviation of the proportional hit of elite women's shooting performances, for each single race's Top-3, Top-10 and Top-30. The competitions are categorized by type of shooting conditions: individual (for sprint and individual competitions) and grouped (for pursuit and mass start competitions). The data are from season 2009/10 to 2016/17 and from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

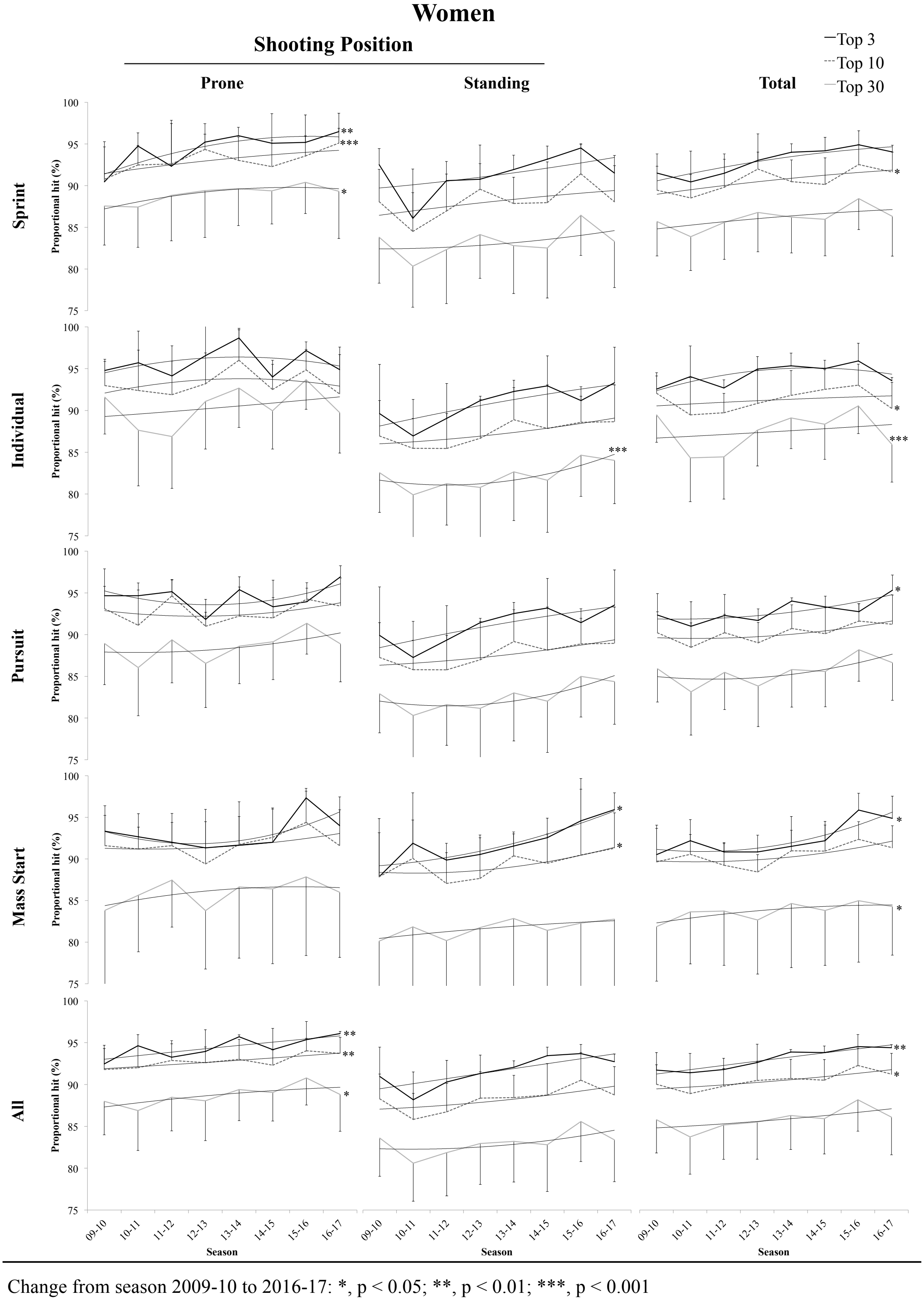
Figure 6: Male biathletes' shooting precision



Change from season 2009-10 to 2016-17: *, p < 0.05; **, p < 0.01; ***, p < 0.001

Average, standard deviation and second-degree polynomial of the proportional hit of elite men's shooting performances, for each single race's Top-3, Top-10 and Top-30. Data are separated by season, by type of shooting and by competition and grouped by shooting and competition. The data comprise four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

Figure 7: Female biathletes' shooting precision



Change from season 2009-10 to 2016-17: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$

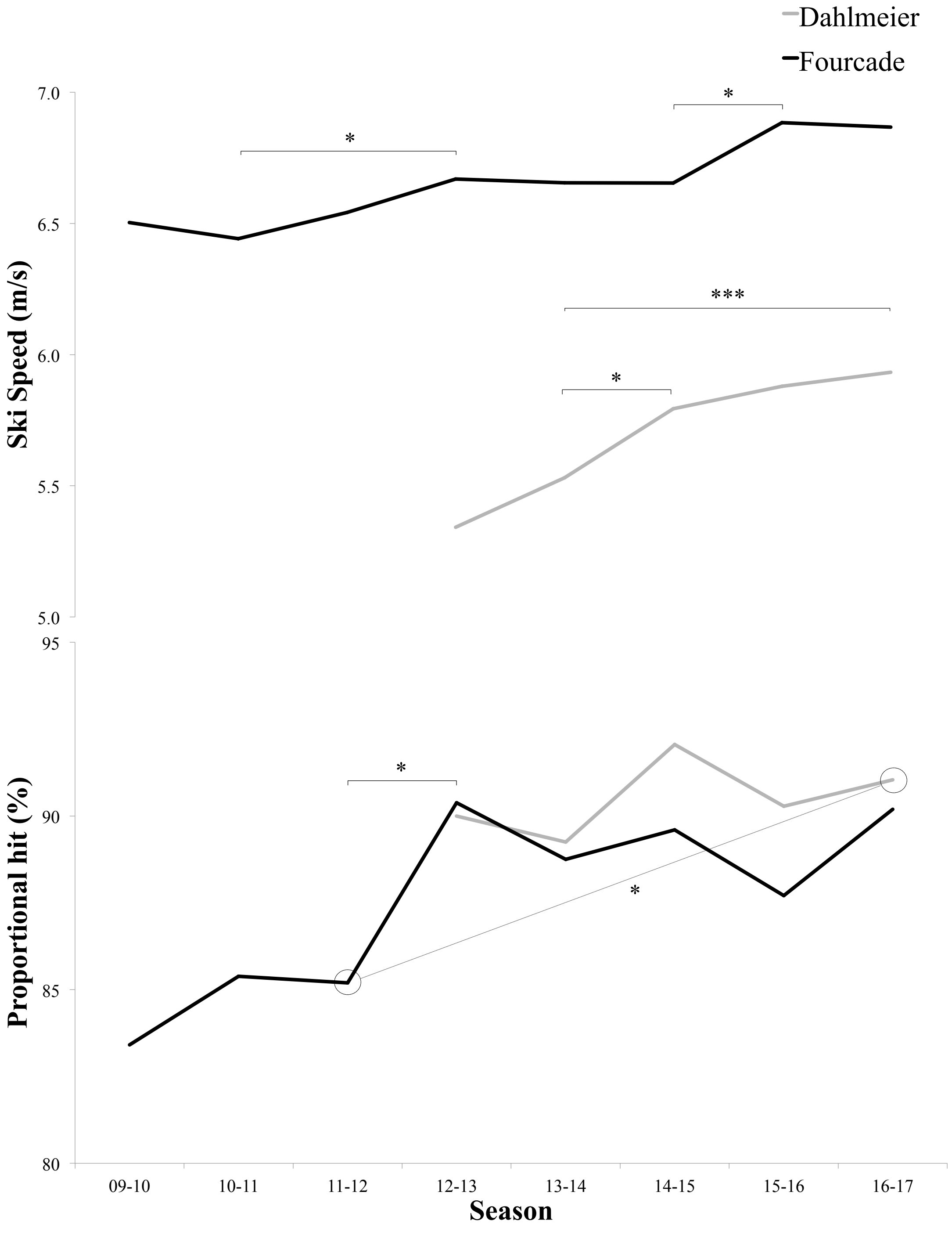
Average, standard deviation and second-degree polynomial of the proportional hit of elite women's shooting performances, for each single race's Top-3, Top-10 and Top-30. Data are separated by season, by type of shooting and by competition and grouped by shooting and competition. The data comprise four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

Table 4: Ranking comparison between Dahlmeier and Fourcade

	Season:	**08-09**	**09-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**
		Number of Victories								
SINGLE RACES	Dahlmeier L.							2	5	10
	Fourcade M.		3	3	8	10	7	8	10	14
SMALL GLOBES	Dahlmeier L.									2
	Fourcade M.		1		2	4	3	2	4	4
		IBU World Cup Overall Ranking								
	Dahlmeier L.					35	15	8	6	1
	Fourcade M.	24	5	3	1	1	1	1	1	1

Laura Dahlmeier and Martin Fourcade's total number of single races and IBU World Cup small crystal globe victories and IBU World Cup overall rankings. The data are separated by season. Single victories are comprised of four competitions: sprint, individual, pursuit and mass start, and are from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

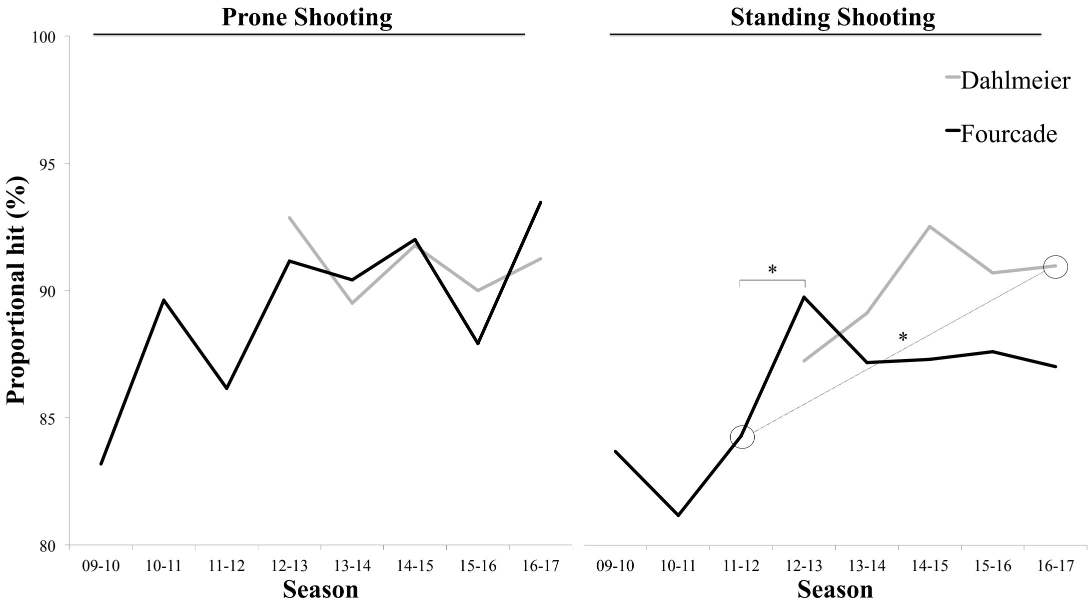
Figure 8: Performance comparison between Dahlmeier and Fourcade



Inter-seasonal difference on same-biathlete's performances and same age comparison between the biathletes' performances: *, p < 0.05; ***, <0.001

Average of Laura Dahlmeier and Martin Fourcade's skiing speed and proportional hit, separated by biathlete and season. The data are comprised of four competitions: sprint, individual, pursuit and mass start, and are from four types of events: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

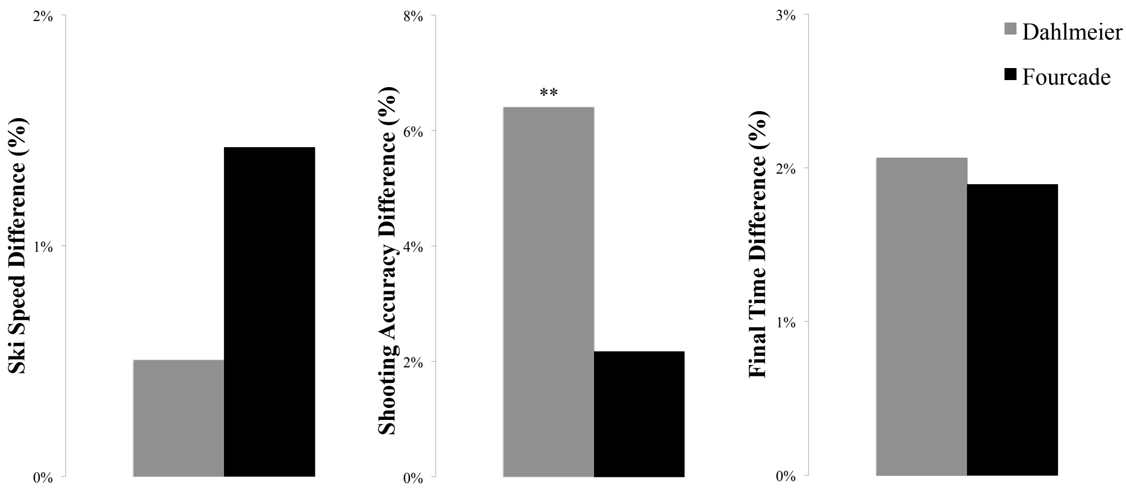
Figure 9: Shooting comparison between Dahlmeier and Fourcade



Inter-seasonal difference on same biathlete's performances and same age comparison between the biathletes' performances: *, $p < 0.05$

Average of Laura Dahlmeier and Martin Fourcade's prone and standing shooting, separated by biathlete and season. The data are comprised of four competitions: sprint, individual, pursuit and mass start, and are from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.

Figure 10: Comparison between Dahlmeier, Fourcade and the overall Top-5



Difference with the other same gender Top-5 athletes: **, $p < 0.01$

Laura Dahlmeier and Martin Fourcade's performances compared to the other four athletes ranked in the Top-5 in the IBU World Cup overall ranking, according to gender. The data comprise season 2016/17 and are separated by skiing speed, shooting accuracy and final time, calculated on all the athletes' competition averages. The data include four competitions: sprint, individual, pursuit and mass start, and are from four types of event: IBU Cup, IBU World Cup, IBU World Championships and Olympic Winter Games.