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Aiming strategy affects performance related factors in biathlon standing shooting

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ABSTRACT

This study focused on investigating differences in shooting performance and performance related factors between two different aiming strategies (HOLD, low radial velocity during the approach 0.4-0.2 seconds before triggering, and TIMING, high radial velocity) in biathlon standing shooting. 23 biathletes fired 8x5 standing shots at rest (REST) and 2x5 shots during a race simulation (RACE). Shooting performance (hit point distance from the center of the target), aiming point trajectory and postural balance were measured from each shot. Shooting performance was similar both at REST (HOLD 33±5 mm vs TIMING 38±8 mm, $p=0.111$) and in RACE (40±11 mm vs 47±12 mm, $p=0.194$). Better shooting performance was related to smaller distance of the aiming point mean location (REST $r=0.93$, $p<0.001$, RACE $r=0.72$, $p=0.018$) and higher time spent within ⅔ of the distance of the hit area edge from the center 0.6-0.0 seconds before triggering (REST $r=-0.88$, $p=0.001$, RACE $r=-0.73$, $p=0.016$) in HOLD, and to lower aiming point total velocity 0.6-0.0 seconds before triggering (REST $r=0.77$, $p=0.009$, RACE $r=0.88$, $p=0.001$) and less aiming point movement 0.2-0.0 seconds before triggering (REST $r=0.82$, $p=0.003$, RACE $r=0.72$, $p=0.012$) in TIMING. Postural balance was related to shooting performance at REST in both groups and in RACE in TIMING. Biathletes using the hold strategy should focus on stabilizing the aiming point before triggering and aiming at the center, whereas biathletes using the timing strategy benefit of decreasing the total velocity during the final approach as well as minimizing the aiming point movement right before triggering.

KEYWORDS

biomechanics, optoelectronics, postural balance, biathlon, rifle shooting, technique, coaching

INTRODUCTION

Biathlon is an Olympic winter sport combining cross-country skiing and rifle shooting where the total performance is determined by the skiing speed, shooting accuracy and shooting time. The high intensity skiing is interrupted two or four times during the competition (depending on the competition type) during which the shooting both in the prone or standing position is performed under recovery from high intensity skiing[1]. The shooting is performed with small-bore rifles and during each shooting occasion in individual competitions five shots are fired to the targets 50m away from the shooting lane. It has been proposed that in the biathlon sprint the shooting accuracy explains roughly 30% of the performance[2,3] whereas in the individual competition, the only competition where time penalty is used, the shooting accuracy may explain as much as 50% of the total performance[4].

The postural sway response to exercise depends on the type of exercise[5], highlighting the need for sport-specific testing patterns. Generally, postural sway in normal quiet standing has been found to increase when the exercise intensity exceeds the lactate accumulation threshold[6]. Both aerobic[7] and anaerobic[7,8] exercise protocols seem to decrease postural control, and what's interesting regarding biathlon, recovery of postural control after these two types of exercises is similar, taking 8 – 13 minutes[7,8]. Hence, biathletes should try to control their skiing intensity so that they would not encounter too much fatigue before they have completed all shootings, because they do not have time to wait for the recovery of postural control during competitions.

High intensity skiing prior to shooting destabilizes the body posture in standing shooting[6,9,10] and thereby affects the body sway during shooting mostly in anteroposterior direction[11]. Body sway is also related to rifle stability/rifle motion[11-13] which has been shown to associate closely with shooting accuracy[14-17] and also differentiates high- and low-score shooters[11,12,15,18-20]. Rifle sway both in horizontal[12,21] and vertical[13] direction has been proposed to exert negative effect on shooting performance.

From another point of view, in standing rifle shooting with a low time pressure and the performance mostly determined by accuracy (points), the rifle precision shooters are using a shooting strategy based on holding the aiming point at as middle of the target as possible before triggering[22,23]. However, in biathlon standing shooting with a higher time pressure (the shooting time is included in the total performance) and no points are counted but only hits, some biathletes choose to use another aiming strategy (timing). In timing aiming strategy, the biathlete tries to control the movement of the rifle towards the target as well as possible and times the triggering when approaching the target. This strategy could enable biathletes to perform the shooting faster than when using the holding strategy.

Taken all together, previous studies on biathlon standing shooting have proposed several different factors that are related to shooting accuracy, yet correlations of the proposed technical factors to shooting performance have been moderate at the most and to some extent controversial. Related to different shooting strategies, Goodman et al[23] suggested that differences in the strategy in rifle precision shooting could be observed by inspecting the distance-time profiles of the aiming point, but rifle precision shooters do not demonstrate different strategies. Further, Ihalainen et al[13] suggested recently that differences in the strategy in biathletes could be observed by inspecting the aiming point trajectory visually. However, different shooting strategies have not been studied in biathlon shooting so far.

The aim of the present study was to use the aiming point trajectory data to classify biathletes' standing shooting strategies. Contrary to the findings in the study by Goodman et al[23] on rifle precision shooting, biathletes are hypothesized to demonstrate different aiming strategies, observed as different mean distance-time profiles. The second aim was to investigate whether shooting performance and shooting technical factors are affected by two different aiming strategies (hold and timing). Based on previous suggestions by Ihalainen et al[13], it is hypothesized that aiming accuracy is related to shooting performance in biathletes using the hold strategy but not in biathletes using the timing strategy. Postural balance is hypothesized to be related to shooting performance regardless of aiming strategy[11-13,24]. The third aim was to investigate whether the effect of a race simulation on shooting performance and shooting technical factors is different between these two strategies. Based on previous studies reporting effects of a race simulation on biathlon standing shooting[11,13,24], it is hypothesized that shooting performance, shooting technical level and postural balance decrease similarly in both strategies after a race simulation.

MATERIALS AND METHODS

Participants

11 female and 12 male biathletes from the national A-team of Finland (4 female, 4 male; age 25.5 ± 2.7 years), the national development team of Finland (4 female, 2 male; age 21.2 ± 2.0 years) and Vuokatti-Ruka Sports Academy (3 female, 6 male; age 17.0 ± 0.8 years) volunteered for the study. Some of the data was the same as used in the study by Ihalainen et al[13] but more subjects were recruited for the present study. All subjects were informed of the purpose, nature and potential risks of the study, and they gave their written informed consent prior to participating the measurements. The study was conducted according to the declaration of Helsinki, and ethical approval was granted by the University of Jyväskylä Ethical Committee.

Experimental task

All subjects performed the same testing protocol as in the study by Ihalainen et al[13]. First, all athletes performed a biathlon standing shooting task of 4x5 shots in a resting state. This was followed by a maximal incremental roller skiing test on a large motor-driven treadmill until exhaustion using the V2 skate skiing technique. Before starting the maximal incremental test, the subjects performed a 10-minute warm-up with a speed of 6.5 km/h for junior women, 8 km/h for junior men and senior women, and 9.5 km/h for senior men. The inclination was 3º in all cases. The same speed and inclination were also used as the initial workload for the incremental test. During the incremental test, the speed of the treadmill was increased by 1.5 km/h every 3 minutes until volitional exhaustion, whereas inclination was the same throughout the test. At the end of each 3-minute stage, the treadmill was stopped for 15-20 seconds to collect a blood lactate sample. This was included in the 3-minute stage. After the test, the subjects first underwent a passive recovery period for 5 minutes and then performed a cool-down of 10 minutes by skiing on the treadmill at the initial workload for the test. After the recovery period the same shooting task of 4x5 shots in a resting state was performed again. Based on the incremental test, the speed at which 95% of the measured peak heart rate would be achieved was evaluated from the heart rate vs velocity curve. Finally, the athletes performed a race simulation of 2x5 min at the intensity of 95% of peak heart rate, performing a shooting task of 5 standing shots right after both 5-minute bouts.

Shooting was performed in the standing position on force platforms close to the treadmill so that the participant was ready for shooting within 45 seconds after each race simulation bout.

Data collection

All physiological assessments were performed during roller skiing on a motorized treadmill OJK-2 (Telineyhtymä, Kotka, Finland) with the skate skiing sub-technique V2. All subjects used Marwe Skate 610 A (Polymer Components Finland Oy, Hyvinkää, Finland) roller skis (rolling resistance moderate / 6).

Heart rate was monitored continuously throughout the test protocol with a heart rate monitor Polar V800 (Polar Electro Oy, Kempele, Finland). Peak heart rate and heart rate at each submaximal stage as well as during the race simulation were determined as the highest 5-second mean values.

A capillary (fingertip) blood sample for determining the blood lactate concentration was taken after each stage of the maximal incremental test, 1 minute after the maximal incremental test, and right after the shooting during the two race simulation bouts. The samples were analyzed with a Biosen C-Line blood lactate analyzer (EKF-diagnostic GmbH, Barleben/Magdeburg, Germany).

The shooting tasks were carried out indoors with a 10-meter shooting distance into a scaled target using Noptel ST 2000 training device (Noptel Inc, Oulu, Finland). The device consisted of an optical transmitter-receiver unit weighting 80 g attached to the barrel of the gun and a reflector attached around the targets. The hit point and aiming point trajectory of each shot were recorded at 67 Hz sampling rate. The optical unit was connected to a laptop for data visualization, analysis and storage. All subjects used their own rifles in the shooting tasks. Multiple variables representing shooting performance and different shooting technical components were analyzed from the aiming point trajectory data (Table 1). Before the first rest shooting series, the zeroing of the rifle was performed with the assistance of a stable support under the rifle. The subjects were instructed to shoot at their normal competition rhythm and technique.

The shooting was performed standing on round-shaped styrofoam plates placed on two AMTI force platforms (one under each ski) (Advanced Mechanical Technology Inc, Watertown, USA). The signals were amplified and collected at 1000 Hz using the wireless Coachtech system

(University of Jyväskylä, Vuokatti, Finland). Triggering moment was identified from the balance data based on microphone data collected synchronously with the same system. Center of pressure (COP) coordinate data was filtered with fourth-order zero-phase lag digital low pass filter with 10 Hz cutoff frequency, as recommended by Ruhe et al[25]. Postural balance was measured as standard deviation of the COP location in the shooting direction (SDY) and cross-shooting direction (SDX) during the last 0.6 seconds before triggering. COP was calculated for both legs separately from the momentum and the force signals acquired from the force plates. Whole body COP was calculated utilizing the left and right leg COP locations and the force signals. Postural balance variables are described in Table 1.

A mean distance-time profile was composed for all subjects separately for shooting in a resting state and during the race simulation. For this profile, a mean distance value of all shots at each time point from 0.6 seconds before triggering to the moment of triggering was used, as in the study by Goodman et al[23]. Based on the mean distance values at each time point, the approach velocity (AV) was defined as the mean radial velocity between 0.4 and 0.2 seconds before triggering (i.e. the rate of change of the distance between the center of the target and the aiming point). (Figure 1).

The biathletes were sorted by their rest shooting AV during this time period and split into two groups. Those 10 biathletes demonstrating the lowest AV made up the HOLD strategy group (2 men, 8 women; 4 national A-team, 4 national development team, 2 Vuokatti-Ruka Sports Academy) and those 10 biathletes demonstrating the highest AV made up the TIMING strategy group (8 men, 2 women; 3 national A-team, 2 national development team, 5 Vuokatti-Ruka Sports Academy). Despite different sample distribution by gender in the HOLD and TIMING groups, female and male biathletes were not separated because studies have shown that females and males have similar shooting performance both in biathlon[2] and in air rifle shooting[26,27], and because no performance differences were observed between the two groups (table 2). A mean distance-time profile was composed for both groups from the individual mean profiles of the subjects in each group. Hence, three athletes from the middle were excluded from the analyses to increase the differences between the groups while keeping the sample size reasonable.

Statistical methods

Shapiro-Wilk's test was used to test the normality of the data. Variables violating the normality assumption were treated with a natural logarithm transformation to meet the requirements of normality distribution.

Shooting performances in a resting state before and 15 minutes after the incremental maximal roller skiing test were compared using the Wilcoxon Signed-Ranks test, as the data violated the normality assumption. As no statistically significant differences were observed, the mean value of all 40 resting shots was used to represent shooting in a resting state (REST). The Student's t-test for dependent samples was used to compare shots fired after the first and the second race simulation bout, as the data met the normality assumption. No statistically significant differences were observed in those either, and therefore the mean value of all 10 race simulation shots was used to represent shooting during race simulation (RACE).

The independent samples t-test was used to investigate differences between HOLD and TIMING groups in physiological measures of the incremental skiing test and race simulation. A two-way repeated measures ANOVA with Huynh-Feldt correction was used to analyze the effects of shooting condition (REST vs RACE) and aiming strategy (HOLD vs TIMING) to shooting performance, shooting technical variables and postural balance together with Bonferroni post hoc test. Two-tailed Pearson correlation coefficients were computed to examine the relationship between shooting performance and aiming point trajectory and postural balance variables at REST and in RACE in both aiming strategy groups (HOLD and TIMING).

All data and results are reported as the mean ± standard deviation or the mean ± 95% confidence interval, and statistical significance was set at $p < 0.05$. All statistical analyses were conducted with IBM SPSS Statistics 22.0 software (IBM Corp., Armonk, NY, USA).

RESULTS

The HOLD and the TIMING groups achieved a similar maximal speed during the maximal incremental test (16.3 ± 1.7 km/h vs 17.4 ± 2.2 km/h, p = 0.251) and performed the race simulation using a similar speed as well (13.8 ± 1.4 km/h vs 13.9 ± 1.7 km/h, p = 0.810). Both groups also demonstrated similar relative heart rates during the race simulation (HOLD 97 ± 1% vs TIMING 97 ± 2% of maximal heart rate, $p = 0.296$) as well as similar blood lactate values after the race simulation (HOLD 7.1 ± 2.2 mmol/L vs TIMING 6.5 ± 1.4 mmol/L, $p = 0.476$).

Distance-time profiles and approach velocity (AV) values are illustrated in Figure 2. The race simulation increased the AV (REST 100 ± 52 mm/s vs RACE 146 ± 67 mm/s), observed as a significant main effect of the shooting condition $F(1,18) = 21.960$, $p < 0.001$. The TIMING group demonstrated a higher AV compared to HOLD both at REST (+162%; $p < 0.001$) and in RACE (+87%; $p = 0.002$), and the main effect of aiming strategy was significant $F(1,18) = 43.109$, $p < 0.001$. In the HOLD group, AV increased more from REST to RACE than in the TIMING group, observed as a significant interaction effect between shooting condition and aiming strategy $F(1,18) = 5.577$, $p = 0.030$. In the HOLD group, AV increased 78% from REST to RACE ($p < 0.001$), whereas in the TIMING group the 27% increase was not significant ($p = 0.118$).

The race simulation caused a decrease in the shooting performance (SP) and shooting technical level, observed as significant main effects of the shooting condition (REST vs RACE) for SP and all shooting technical variables, except for inter-shot time interval for which the main effect was only tendential (Table 2). All other shooting technical variables were affected by aiming strategy but not inter-shot time interval, observed as significant main effects of the aiming strategy. The aiming strategy did not influence SP. Horizontal stability of hold (DevX) decreased more from REST to RACE in the HOLD than in the TIMING group, observed as a significant interaction effect between the shooting condition and aiming strategy. The race simulation also attenuated postural balance, observed as significant main effects of the shooting condition for most postural balance variables whereas aiming strategy did not influence postural balance (Table 3).

In the HOLD group, shooting performance (SP) was related to aiming accuracy (COG) and holding time (HT) both at REST and in RACE (Figure 3), as well as to shooting direction postural balance (SDY) at REST ($r = 0.64$, $p = 0.045$). The absolute changes from REST to RACE in COG and HT were related to the absolute changes in postural balance in shooting direction (Figure 4), and the absolute change from REST to RACE in SP tended to correlate with the absolute change in HT ($r = -0.61$, $p = 0.060$) in the HOLD group.

In the TIMING group, shooting performance (SP) was related to absolute triggering value (ATV), mean velocity (MV) and timing of triggering ($TIRE_6$) both at REST and in RACE (Figure 5). Also, the rear leg balance in shooting direction (SDY_R) was related to SP in both conditions (REST r = 0.73, p = .017; RACE r = 0.66, p = 0.038). Further, the absolute change from REST to RACE in SP tended to correlate with the absolute change in MV in the TIMING group (r = 0.57, p = 0.085).

DISCUSSION

The aims of the present study were 1) to classify biathletes' aiming strategies (hold and timing) based on aiming point trajectory data, 2) to investigate differences in shooting performance and performance determining factors between these two different aiming strategies, and 3) to investigate the effects of a race simulation on shooting performance and performance determining factors in biathletes using two different aiming strategies. The approach velocity calculated from the aiming point trajectory data was able to classify biathletes into two aiming strategy groups, hold and timing. The results showed that even though the shooting performance did not differ between the aiming strategy groups, the most important performance determining factors were different for the hold and the timing strategy. In biathletes using the hold strategy, aiming accuracy and holding time were related to shooting performance. In biathletes using the timing strategy, the most important factors were the absolute triggering value, mean velocity and timing of triggering. Shooting performance, postural balance and all shooting technical variables, with the exception of timing of triggering (increased from rest to race shooting), were compromised after the race simulation in both groups.

Previous studies[22,23] in rifle precision shooting have reported similar aiming strategies in all shooters. All seem to try to hold the aiming point still before triggering, demonstrating similar shapes in the time profiles of aiming point movement[22,23]. In the present study, some biathletes tried to stabilize the aiming point inside the hit area well before triggering demonstrating only minor changes in the distance from the center of the target during 0.4-0.2 seconds before triggering (Figure 2). This behavior was similar to that observed in the previous rifle shooting studies[22,23], and hence it was classified as the hold strategy. However, some biathletes acted differently, demonstrating a much higher rate of change of the distance between the center of the target and the aiming point during 0.4-0.2 seconds before triggering (Figure 2). This behavior was classified as the timing strategy, supporting the first study hypothesis. Due to both strategy groups demonstrating similar shooting performance, it could be suggested that both strategies could be efficient when the technical skill level is mastered. It is worth noting that similar profiles were observed both at rest and in race shooting, but more overlapping between biathletes could be observed in the latter (Figure 2). This is most likely because in the present study the groups were distinguished based on rest shooting values, leaving a more in-depth analysis of possible individual changes in the strategy from rest to race shooting a topic for future studies with a higher number of participants.

In the present study, the most important technical factors related to shooting performance were aiming accuracy and holding time for the hold strategy and absolute triggering value, mean velocity and timing of triggering for the timing strategy. Postural balance was important for both. These findings confirm the second study hypothesis.

The aiming accuracy variable that was related to shooting performance in biathletes using the hold strategy in the present study, has also been observed to be related to shooting performance in air rifle[21,28] and air pistol shooting[29]. Further, a similar variable to the holding time variable used in the present study, which was also an important factor for the hold group, has been observed to be related to shooting performance in running target shooting[15]. In biathletes using the timing strategy, aiming accuracy and holding time were not related to shooting performance, as expected. As suggested by Ihalainen et al[13], the results of the present study show that biathletes using the timing strategy are still moving towards the center during the last 0.6 seconds before triggering (Figure 2). As they do not even try to aim at the center or hold the rifle still during that time period, it seems reasonable that aiming accuracy and holding time are not representative of their technical skill level. These findings could be related to the nature of the hold strategy in biathlon shooting being closer to that of rifle precision shooting, whereas different factors should be used to assess the technical level of biathletes using the timing strategy.

The mean velocity variable that was related to shooting performance in biathletes using the timing strategy in the present study, was reported to be related to shooting performance at rest but not in race in the study by Sattlecker et al[11]. Further, the absolute triggering value variable that was also an important factor for the timing group, was related to biathlon standing shooting performance in the study by Ihalainen et al[13] as well. However, the correlation coefficients were lower compared to the present study. These differences and the higher correlation coefficients in the present study might be due to the lack of distinguishing between the different aiming strategies in the previous studies[11,13], as the analyzes have been performed for all biathletes together regardless of the aiming strategy. These findings in the present study might indicate that despite higher approach velocity, biathletes using the timing strategy benefit of decreasing the total velocity during the final approach as well as minimizing the aiming point movement right before triggering, whereas biathletes using the hold strategy should focus on the ability to stabilize the aiming point well inside the hit area and aim at the center during the last 0.6 seconds before triggering. However, confirming the findings of previous studies[11-13,24], postural balance was related to shooting performance in both strategy groups. Thus, regardless of the aiming strategy, a stable posture is a prerequisite of successful shooting performance.

Furthermore, in biathletes using the timing strategy, the timing of triggering variable was significantly related to shooting performance at rest and tendentially in race. The biathlon standing shooting study by Ihalainen et al[13] did not find a significant relationship to shooting performance with timing of triggering. The air rifle shooting study by Ihalainen et al[21] did not find a significant correlation either, but multiple regression analysis showed it to account for 9 % of the variation in shooting score, when other technical components were also taken into account. In the present study, the variable evaluated the timing according to the distance of aiming point mean location in six 0.1-second time sectors before triggering. Thus, the 0.1-second sector during which the aiming point was closest to the center defined the timing points from one to six. In the previous studies[13,21], the variable was similar, but with three 0.2-second sectors and points given from one to three. The findings in the present study indicate that it might be worthwhile to evaluate timing of triggering more precisely at least in biathlon shooting, which is performed under time pressure, taking aiming strategies into account.

In the present study, neither horizontal nor vertical sway of the aiming point was directly related to shooting performance. In addition to the study by Sattlecker et al[11] on biathlon shooting, the same has been observed in running target shooting also[15]. However, controversial results have been reported in biathlon standing shooting studies as well. Sattlecker et al[12] have reported that better shooting performance is related to less horizontal sway and Ihalainen et al[13] that it is related to less vertical sway. This controversy may be related to using the mean values of multiple shots to represent the technical skill level. This is because practice has shown that the approach direction varies between biathletes and the direction from which the final settling at the target occurs may also vary within the individual. As the last 0.6 seconds before triggering has been used to calculate those variables, and due to the fast nature of biathlon shooting, the approach direction might also affect the sway direction. Therefore, the strictly horizontal and vertical measures might be more representative in rifle precision shooting[19,21-23].

Shooting performance, most of the shooting technical variables and postural balance decreased from rest to race shooting, which are in line with previous findings[11,13,24]. Confirming the third study hypothesis, the aiming strategy did not affect the effects of race simulation on these variables. As in the study by Ihalainen et al[13], timing of triggering improved from rest to race shooting in both groups, suggesting that they might rely more on timing the shot correctly when exposed to decreased balance and ability to control the rifle movements. However, the results of the present study also suggest that this might not be the best strategy. In biathletes using the hold strategy, the timing of triggering was not related to shooting performance either at rest or in race. Among them, decreases in postural balance were related to decreases in aiming accuracy and holding time, and decreases in holding time were tendentially related to decreases in shooting performance. Moreover, in biathletes using the timing strategy, the relationship between shooting performance and timing of triggering was weaker and statistically only tendential in race shooting. Among them, increases in mean velocity were tendentially related to decreases in shooting performance. Thus, instead of increasing timing of triggering in race shooting compared to rest shooting, it can be suggested that biathletes should focus on improving the technical work and balance to perform better in shooting under physical load.

An interesting finding of the present study was also that the approach velocity increased from rest to race shooting only in biathletes using the hold strategy. This may be related to difficulties in maintaining the technical skill level due to fatigue or to a change in aiming strategy either on purpose or unintentionally. However, the results of the present study show that the effect of changes from rest to race shooting in approach velocity is not straightforward, as the absolute changes in approach velocity from rest to race shooting were not related to the absolute changes in shooting performance in either group (HOLD $r = 0.02$, $p = 0.96$; TIMING $r = -0.03$, $p = 0.93$). However, the possible effects of changing strategy between rest and race condition on shooting performance and shooting technical factors remain a question for future studies.

There were no differences in postural balance in biathletes shooting with different strategies, and a main effect of shooting condition (rest vs race) was observed regardless of aiming strategy. Therefore, it could be suggested that the observed differences in shooting performance determining factors were not related to postural balance. However, in biathletes using the hold strategy, decreases in postural balance were related to decreases in aiming accuracy and holding time. Such relationships were not observed in biathletes using the timing strategy. Even though we could suggest that based on the present data the technical level in shooters using the hold strategy might be more vulnerable to balance impairments in race shooting, these results should be taken with caution and should not be raised above other findings. First, both groups demonstrated similar shooting performance. Secondly, the shooting performance decreased similarly in both groups after the intense exercise, and thirdly, the significant correlation is likely caused by the single values different from the others (Figure 4). Thus, both strategies could be effective.

Time between shots was not influenced either by aiming strategy nor by the race simulation. However, looking at the mean values, the timing strategy was slightly faster in both conditions and the difference was somewhat larger in race shooting, both groups demonstrating slightly longer times between shots during the race simulation. Still, the unequal number of men and women in each strategy group admits of speculation, as there were eight women and two men among those using the hold strategy, whereas among those using the timing strategy there were two women and eight men. Previous studies by Luchsinger et al have observed negligible[30] and no[2] differences in shooting performance between men and women in the biathlon world cup, whereas both studies reported men to shoot more than 10 % faster[2,30]. Thus, it may be possible that men prefer the timing strategy in the biathlon world cup. This observation might give topics for future studies to investigate the differences in shooting times between biathletes using different aiming strategies in real competition situations, as well as possible gender differences in aiming strategies.

One limitation of the present study is that the shooting was performed using dry firing into a scaled target 10 meters away from the shooter. As the real distance is 50 meters and no real bullets were used, this may affect not only the results per se, but also mentally the way the subjects view the testing situation. Regarding shooting technique, the largest differences are the lack of recoil response of the rifle and the lack of feedback of hit or miss after each shot. These aspects might have influenced the shooting rhythm, even though the biathletes were instructed to shoot using their normal competition rhythm. Nevertheless, the conditions were standardized, and the same technique has been used in previous rifle precision shooting[23,28] and biathlon shooting[13] studies.

Further, the present study used the distance from the center of the target as the measure of shooting performance because from the technical point of view, there is probably not much difference in a shot that hits only slightly inside or slightly outside from the hit area. However, in competitions those small differences define whether a penalty is given or not. Thus, the analyses were also run for hit percentage as the measure of shooting performance, yet with similar findings. Despite not finding substantial differences between these performance measures in the present study, these minor differences can be relevant especially in rifle shooting scoring[31]. The performance based on the distance from the center of the target may not always be the same in all shooting modalities, depending on how the final result is scored. However, in biathlon shooting studies, especially on high level biathletes, the relatively few misses to base the statistical tests on may be misleading, as suggested by Luchsinger et al[4] as well. Hence, future studies on the technical assessment of biathlon shooting are recommended to be aware of these differences when interpreting the results or to use a considerably higher number of shots to base the statistical analyses on.

Another limitation of the present study is that the race simulation included two 5-minute bouts with constant skiing speed and inclination. A typical biathlon competition includes varying terrain with uphills, downhills and flat sections. This forces athletes to vary between the various sub techniques of skate skiing during the entire race[32]. Furthermore, during races biathletes tend to vary their skiing intensity based on which lap they are skiing on[2,4,30]. During each lap they might also use individual pacing strategies into different parts of the track, especially during the last few hundred meters when approaching the shooting range. Thus, future studies should consider exercise protocols more similar to real competitions to improve the ecological validity.

PERSPECTIVE

The results of the present study show a practical significance for biathlon shooting training and testing, as well as open a new perspective for sports scientists to study biathlon shooting. Different aiming strategies should be considered when studying biathlon shooting and when selecting variables for interpretation in testing. Further, variables related to certain directions regarding aiming point movement should be studied more to get a better insight of their relevance in biathlon standing shooting. Biathletes using the hold strategy should focus on improving their aiming accuracy and holding ability. Biathletes using the timing strategy should focus on their ability to approach the target at a controlled velocity and the ability to minimize the movement of the aiming point during the triggering phase. However, a common prerequisite for both aiming strategies seems to be a stable posture. The present findings provide an opportunity to give more individualized feedback from biathlon standing shooting and make it possible to suggest one possibility to distinguish between different ways how athletes might approach biathlon standing shooting strategically. Thus, biathletes and coaches should be aware of the strategy in use and plan the shooting exercises accordingly.

REFERENCES

1. Laaksonen MS, Finkenzeller T, Holmberg H, Sattlecker G. The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: A review. *Journal of Sport and Health Science*. 2018;7(4):394-404.

2. Luchsinger H, Kocbach J, Ettema G, Øyvind Sandbakk. Comparison of the effects of performance level and sex on sprint performance in the biathlon world cup. *International Journal of Sports Physiology and Performance*. 2018;13(3):360-366.

3. Dzhilkibaeva N, Ahrens M, Laaksonen MS. Can performance in biathlon world cup be predicted by performance analysis of biathlon IBU cup? *International Journal of Performance Analysis in Sport*. 2019;19(5):856-865.

4. Luchsinger H, Talsnes RK, Kocbach J, Sandbakk Ø. Analysis of a biathlon sprint competition and associated laboratory determinants of performance. *Frontiers in Sports and Active Living*. 2019;1:60.

5. Zemková E, Hamar D. Physiological mechanisms of post-exercise balance impairment. *Sports Med*. 2014;44(4):437—448.

6. Paillard T. Effects of general and local fatigue on postural control: A review. *Neuroscience & Biobehavioral Reviews*. 2012;36(1):162-176.

7. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *Journal of athletic training*. 2008;43(5):456-463.

8. Yaggie J, Armstrong WJ. Effects of lower extremity fatigue on indices of balance. *J Sport Rehab*. 2004;13(4):312-322.

9. Harkins KM, Mattacola CG, Uhl TL, Malone TR, McCrory JL. Effects of 2 ankle fatigue models on the duration of postural stability dysfunction. *Journal of athletic training*. 2005;40(3):191-194.

10. Bizid R, Margnes E, François Y, et al. Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *Eur J Appl Physiol*. 2009;106(3):375-380.

11. Sattlecker G, Buchecker M, Gressenbauer C, Erich Müller, Lindinger SJ. Factors discriminating high from low score performance in biathlon shooting. *International Journal of Sports Physiology and Performance*. 2017;12(3):377-384.

12. Sattlecker G, Buchecker M, Müller E, Lindinger SJ. Postural balance and rifle stability during standing shooting on an indoor gun range without physical stress in different groups of biathletes. *International Journal of Sports Science & Coaching*. 2014;9(1):171-184.

13. Ihalainen S, Laaksonen MS, Kuitunen S, et al. Technical determinants of biathlon standing shooting performance before and after race simulation. *Scand J Med Sci Sports*. 2018;28(6):1700-1707.

14. Groslambert A, Candau R, Hoffman MD, Bardy B, Rouillon JD. Validation of simple tests of biathlon shooting ability. *Int J Sports Med*. 1999;20(03):179-182.

15. Mononen K, Viitasalo JT, Era P, Konttinen N. Optoelectronic measures in the analysis of running target shooting. *Scand J Med Sci Sports*. 2003;13(3):200-207.

16. Baca A, Kornfeind P. Stability analysis of motion patterns in biathlon shooting. *Human Movement Science*. 2012;31(2):295-302.

17. Mon D, Zakynthinaki MS, Cordente CA, Monroy Antón A, López Jiménez D. Validation of a dumbbell body sway test in olympic air pistol shooting. *PLOS ONE*. 2014;9(4):e96106. https://doi.org/10.1371/journal.pone.0096106.

18. Viitasalo JT, Era P, Konttinen N, et al. The posture steadiness of running target shooters of different skill levels. *Kinesiology*. 1999;31(1):18-28.

19. Konttinen N, Lyytinen H, Viitasalo J. Rifle-balancing in precision shooting: Behavioral aspects and psychophysiological implication. *Scand J Med Sci Sports*. 1998;8(2):78-83.

20. Mason B, Cowan LF, Gonczol T. Biomechanical factors affecting accuracy in pistol shooting. *Excel*. 1990;6(4):2-6.

21. Ihalainen S, Kuitunen S, Mononen K, Linnamo V. Determinants of elite-level air rifle shooting performance. *Scand J Med Sci Sports*. 2016;26(3):266-274.

22. Zatsiorsky VM, Aktov AV. Biomechanics of highly precise movements: The aiming process in air rifle shooting. *Journal of Biomechanics*. 1990;23:35-41.

23. Goodman S, Haufler A, Shim JK, Hatfield B. Regular and random components in aiming-point trajectory during rifle aiming and shooting. *J Mot Behav*. 2009;41(4):367-382.

24. Hoffman MD, Gilson PM, Westenburg TM, Spencer WA. Biathlon shooting performance after exercise of different intensities. *Int J Sports Med*. 1992;13(3):270-273.

25. Ruhe A, Fejer R, Walker B. The test–retest reliability of centre of pressure measures in bipedal static task conditions – A systematic review of the literature. *Gait & Posture*. 2010;32(4):436-445.

26. Mon-López D, Tejero-González CM, Calero S. Recent changes in women's olympic shooting and effects in performance. *PLOS ONE*. 2019;14(5):e0216390. https://dx.doi.org/10.1371/journal.pone.0216390.

27. Goldschmied N, Kowalczyk J. Gender performance in the NCAA rifle championships: Where is the gap? *Sex Roles*. 2016;74:310-322.

28. Ihalainen S, Mononen K, Linnamo V, Kuitunen S. Which technical factors explain competition performance in air rifle shooting? *International Journal of Sports Science & Coaching*. 2018;13(1):78-85.

29. Hawkins R. Identifying mechanic measures that best predict air-pistol shooting performance. *International Journal of Performance Analysis in Sport*. 2011;11(3):499-509.

30. Luchsinger H, Kocbach J, Ettema G, Sandbakk Ø. The contribution from cross-country skiing and shooting variables on performance-level and sex differences in biathlon world cup individual races. *International Journal of Sports Physiology & Performance*. 2019;14(2):190-195.

31. Mon-López D, Tejero-González CM. Validity and reliability of the TargetScan ISSF pistol & rifle application for measuring shooting performance. *Scand J Med Sci Sports*. 2019;29(11):1707-1712. https://dx.doi.org/10.1111/sms.13515. doi: 10.1111/sms.13515.

32. Holmberg H. The elite cross-country skier provides unique insights into human exercise physiology. *Scand J Med Sci Sports*. 2015;25:100-109.

TABLE 1. Aiming point trajectory and postural balance variables.

Component	Variable (unit)	Description
Shooting performance	SP (mm)	Distance of the hit point from the center of the target.
Mean velocity	MV (mm/s)	Mean total velocity of the aiming point trajectory during the last 0.6 seconds before triggering (the total distance travelled by the aiming point / time)
Stability of hold	DevX (mm), DevY (mm)	Horizontal (DevX) and vertical (DevY) standard deviations of the location of the aiming point during the last 0.6 seconds before triggering.
Aiming accuracy	COG (mm)	Distance of the aiming point mean location during the last 0.6 seconds before triggering.
Absolute triggering value	ATV (mm)	Distance travelled by the aiming point during the last 0.2 seconds before triggering.
Timing of triggering	$TIRE_6$ (index)*	Time sector with the smallest distance of mean location: 1 = -0.6...-0.5 s, 2 = -0.5...-0.4 s, 3 = -0.4...-0.3 s, 4 = -0.3...-0.2 s, 5 = -0.2...-0.1 s, 6 = -0.1...0.0 s.
Holding time	HT (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point distance was ≤⅔*57.5 mm (i.e. two thirds of the edge of the hit area).
Inter-shot time interval	Inter-shot time (s)	Mean time interval between two consecutive shots
Postural balance	SDX (mm), SDY (mm)	Standard deviation of the computed whole-body COP location during the last 0.6 seconds before triggering. Cross-shooting direction (SDX), in shooting direction (SDY).
	SDX_F (mm), SDX_R (mm)	Standard deviation of the front (SDX_F) and rear (SDX_R) leg COP location cross-shooting direction during the last 0.6 seconds before triggering.
	SDY_F (mm), SDY_R (mm)	Standard deviation of the front (SDY_F) and rear (SDY_R) leg COP location in shooting direction during the last 0.6 seconds before triggering.

*Previously[13,21] TIRE has been divided into three categories (1 = -0.6…-0.4 s, 2 = -0.4…-0.2 s, 3 = -0.2…0.0 s). $TIRE_6$ with six categories was developed to meet the needs of biathlon shooting.

TABLE 2. Shooting technical variables (mean ± SD) in the HOLD and the TIMING group at REST and in RACE.

		SP	MV	DevX	DevY	COG	ATV	$TIRE_6$	HT	Inter-shot time
REST	TIMING	38 ± 8**	340 ± 49***††	27 ± 7††	24 ± 7**††	47 ± 9***†††	67 ± 9***††	4.9 ± 0.5*†††	35 ± 8**†††	3.13 ± 0.76
	HOLD	33 ± 5*	273 ± 30***	19 ± 2**	15 ± 3**	24 ± 5*	54 ± 6***	4.1 ± 0.2**	66 ± 12***	3.36 ± 0.54
RACE	TIMING	47 ± 12	409 ± 51†	27 ± 5	28 ± 8††	59 ± 12†††	84 ±13†††	5.2 ± 0.3†††	24 ± 7†††	3.23 ± 0.77
	HOLD	40 ± 11	351 ± 41	24 ± 6	19 ± 4	31 ± 10	70 ± 9	4.4 ± 0.4	51 ± 15	3.63 ± 0.83
Main effect of shooting condition	F(1,18)	16.206	102.922	8.956	23.027	27.513	55.506	15.036	31.334	3.310
	p	0.001	<0.001	0.008	<0.001	<0.001	<0.001	0.001	<0.001	0.086
Main effect of aiming strategy	F(1,18)	2.557	11.987	7.367	14.770	41.243	13.974	32.128	46.401	1.076
	p	0.127	0.003	0.014	0.001	<0.001	0.002	<0.001	<0.000	0.313
Interaction effect	F(1,18)	0.307	0.362	5.655	0.177	2.894	0.031	0.213	0.662	0.723
	p	0.586	0.555	0.029	0.679	0.106	0.863	0.650	0.426	0.406

SP shooting performance, MV mean velocity, DevX horizontal stability of hold, DevY vertical stability of hold, COG aiming accuracy, ATV absolute triggering value, $TIRE_6$ timing of triggering, HT holding time, Inter-shot time inter-shot time interval.

Statistically significant difference between REST and RACE, *p < 0.05, **p < 0.01, ***p < 0.001.

Statistically significant difference between TIMING and HOLD, †p < 0.05, ††p < 0.01, †††p < 0.001.

TABLE 3. Postural balance variables (mean ± SD) in the HOLD and the TIMING group at REST and in RACE.

		SDX	SDY	SDX_F	SDY_F	SDX_R	SDY_R
REST	TIMING	0.69 ± 0.12	0.78 ± 0.15*	0.73 ± 0.14*	0.38 ± 0.14*	0.74 ± 0.20*	0.23 ± 0.05**
	HOLD	0.66 ± 0.17	0.58 ± 0.15**	0.67 ± 0.16	0.28 ± 0.13*	0.75 ± 0.25	0.20 ± 0.08*
RACE	TIMING	0.80 ± 0.17	0.95 ± 0.21	0.87 ± 0.21	0.47 ± 0.21	0.97 ± 0.27	0.33 ± 0.10
	HOLD	0.73 ± 0.23	0.81 ± 0.37	0.75 ± 0.26	0.34 ± 0.18	0.93 ± 0.45	0.25 ± 0.06
Main effect of shooting condition	F(1,18)	4.118	13.098	6.469	11.918	11.219	20.808
	p	0.057	0.002	0.020	0.003	0.004	<0.001
Main effect of aiming strategy	F(1,18)	0.484	3.483	1.483	2.429	0.006	3.908
	p	0.495	0.078	0.239	0.136	0.937	0.064
Interaction effect	F(1,18)	0.210	0.288	0.511	0.008	0.160	1.866
	p	0.652	0.598	0.484	0.928	0.694	0.189

Postural balance (standard deviation of the center of pressure location 0-0.6 s before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (SD*_F, front; SD*_R, rear).

Statistically significant difference between REST and RACE, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

FIGURE LEGENDS

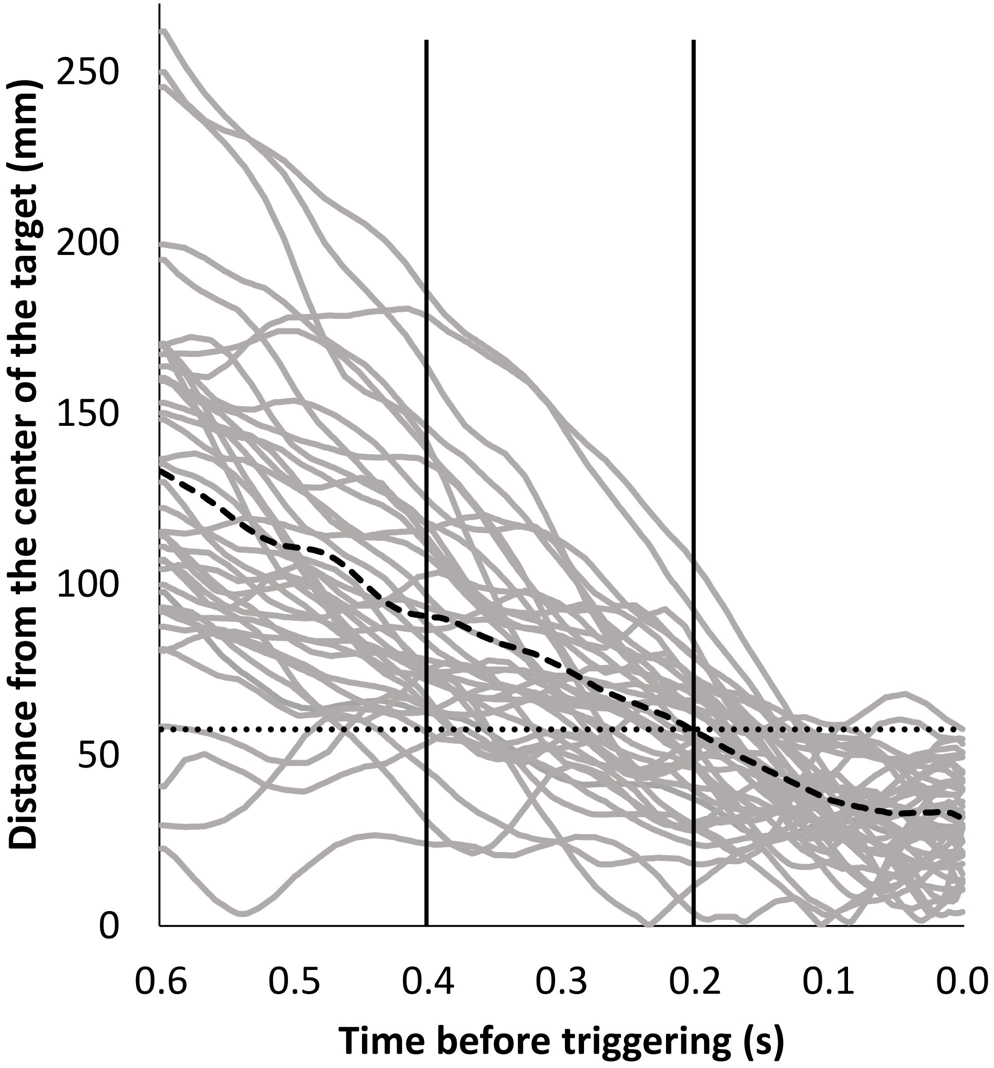
FIGURE 1. Distance-time profiles for all shots (solid lines) and the mean distance-time profile (dashed line) of one subject at REST. The horizontal dotted line represents the outer edge of the hit area of the target (57.5 mm). The mean distance-time profile between the two vertical lines (0.4 to 0.2 s before triggering) was used to calculate the approach velocity.

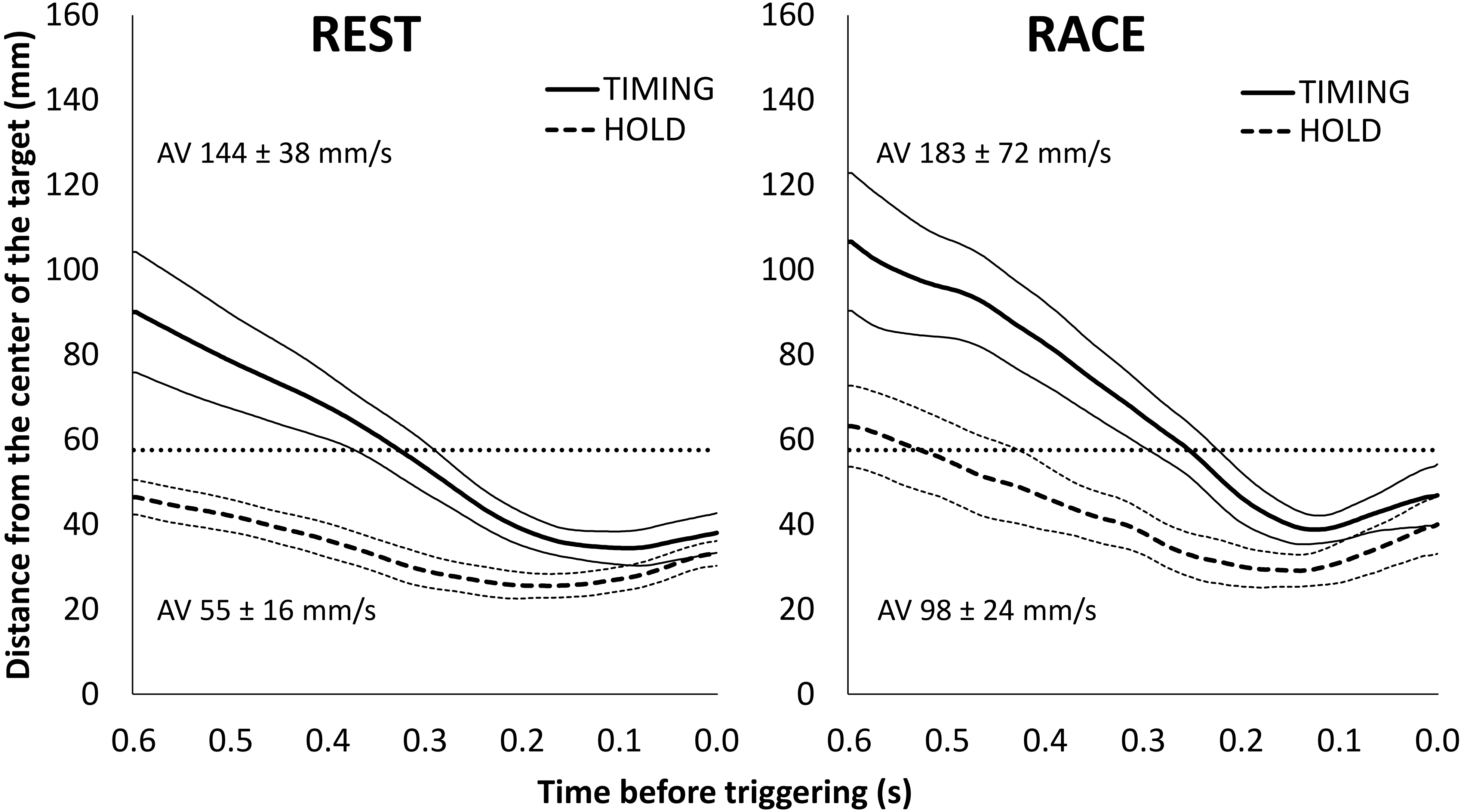
FIGURE 2. Distance-time profiles and approach velocity (AV) values at REST and in RACE in the HOLD and the TIMING group. The thick lines represent the mean profiles and the thin lines represent the 95% confidence interval profiles. The horizontal dotted line represents the outer edge of the hit area of the target (57.5 mm).

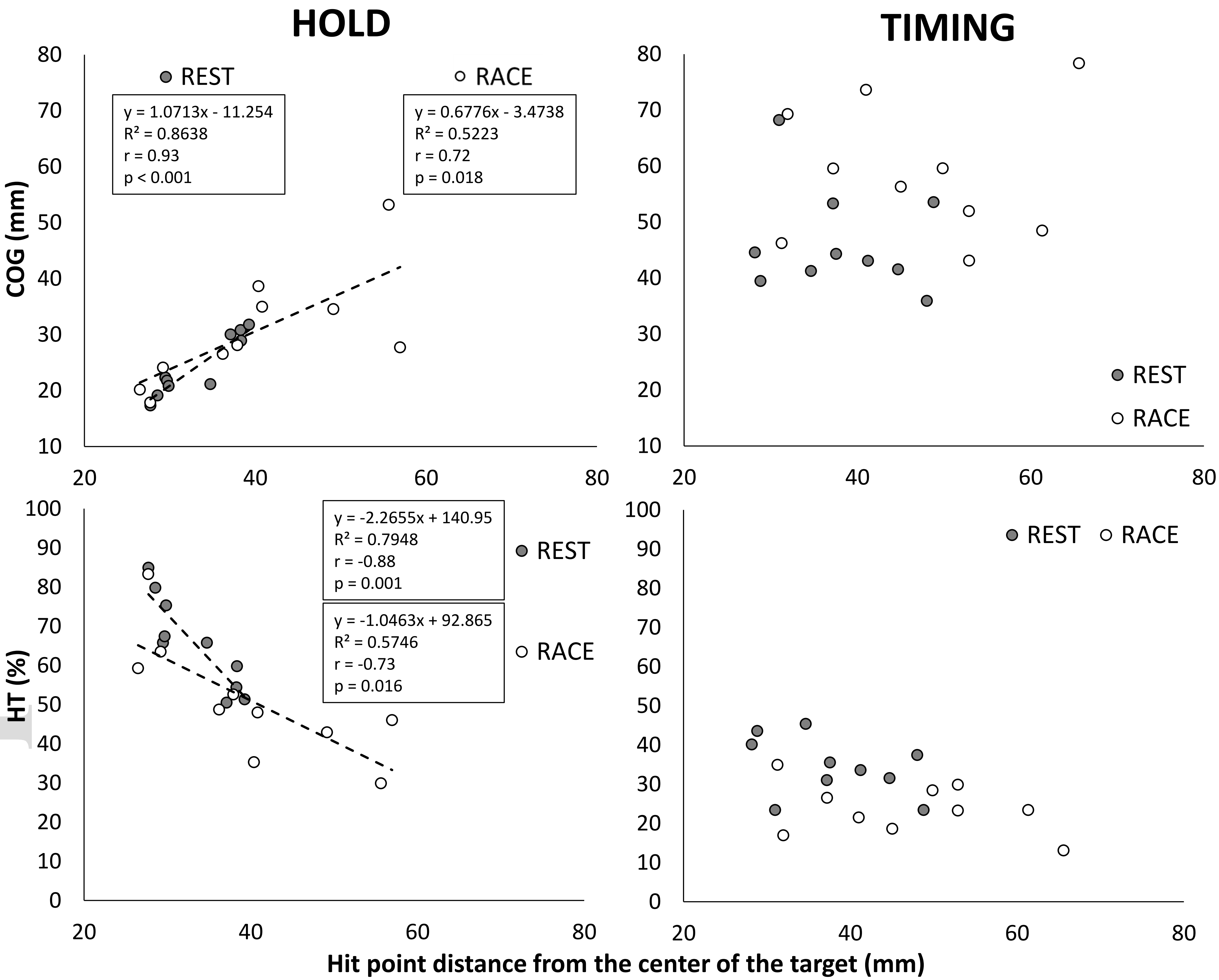
FIGURE 3. The correlations between hit point distance from the center of the target (shooting performance, SP) and aiming accuracy (COG), and SP and holding time (HT) in the HOLD and the TIMING groups at REST and in RACE.

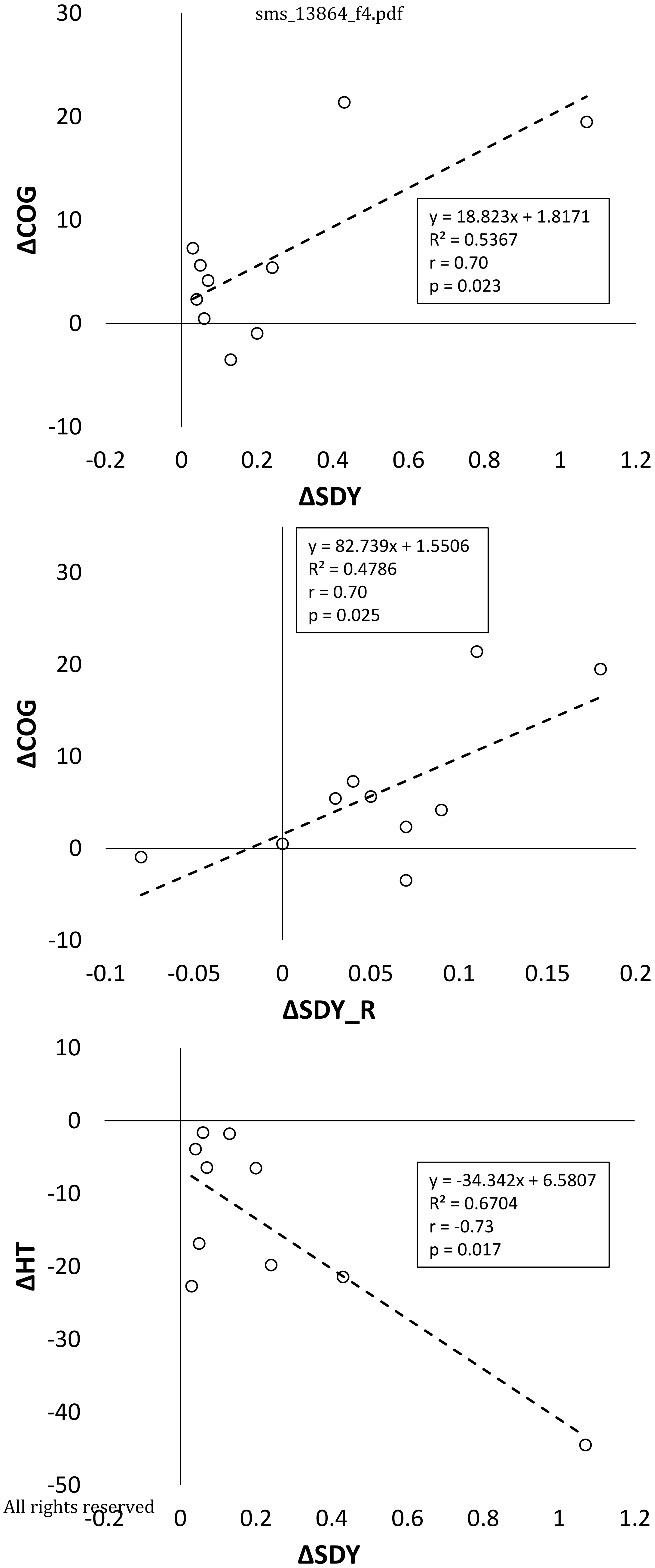
FIGURE 4. The correlations between the absolute changes from REST to RACE in the HOLD group in aiming accuracy (ΔCOG) and whole body balance in shooting direction (ΔSDY), ΔCOG and rear leg balance in shooting direction (ΔSDY_R), and holding time (ΔHT) and ΔSDY.

FIGURE 5. The correlations between hit point distance from the center of the target (shooting performance, SP) and absolute triggering value (ATV), SP and mean velocity (MV), and SP and timing of triggering ($TIRE_6$) in the HOLD and the TIMING groups at REST and in RACE.

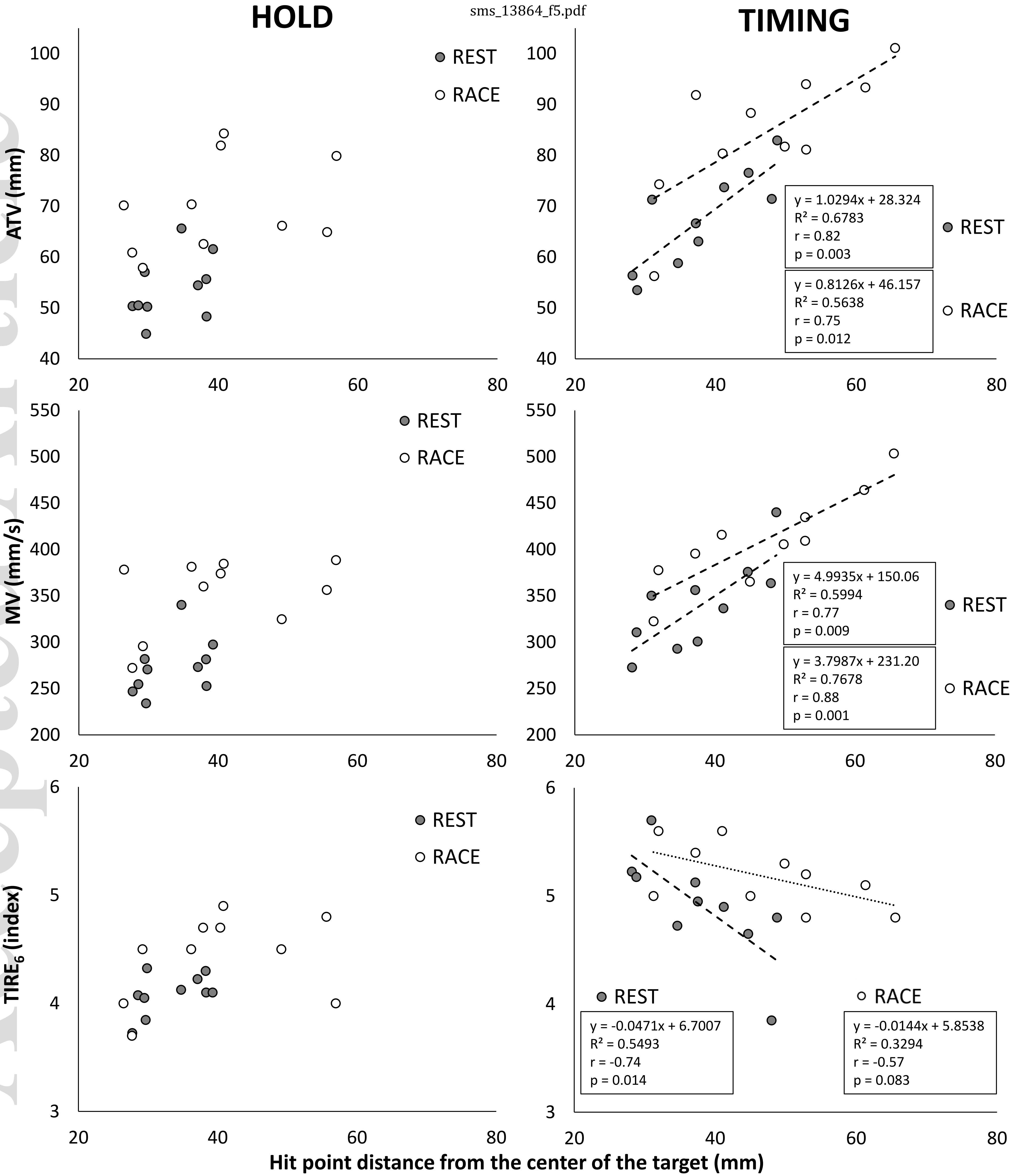

Distance from the center of the target (mm)
250
200
150
100
50
0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Time before triggering (s)


REST
RACE
TIMING
HOLD
AV 144 ± 38 mm/s
AV 55 ± 16 mm/s
AV 183 ± 72 mm/s
AV 98 ± 24 mm/s
Distance from the center of the target (mm)
160
140
120
100
80
60
40
20
0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Time before triggering (s)


HOLD
TIMING
COG (mm)
HT (%)
REST
RACE
y = 1.0713x - 11.254
R² = 0.8638
r = 0.93
p < 0.001
y = 0.6776x - 3.4738
R² = 0.5223
r = 0.72
p = 0.018
y = -2.2655x + 140.95
R² = 0.7948
r = -0.88
p = 0.001
y = -1.0463x + 92.865
R² = 0.5746
r = -0.73
p = 0.016
Hit point distance from the center of the target (mm)



ΔCOG
ΔSDY
y = 18.823x + 1.8171
R² = 0.5367
r = 0.70
p = 0.023
ΔCOG
ΔSDY_R
y = 82.739x + 1.5506
R² = 0.4786
r = 0.70
p = 0.025
ΔHT
ΔSDY
y = -34.342x + 6.5807
R² = 0.6704
r = -0.73
p = 0.017


HOLD
TIMING
ATV (mm)
MV (mm/s)
TIRE6 (index)
REST
RACE
y = 1.0294x + 28.324
R² = 0.6783
r = 0.82
p = 0.003
y = 0.8126x + 46.157
R² = 0.5638
r = 0.75
p = 0.012
y = 4.9935x + 150.06
R² = 0.5994
r = 0.77
p = 0.009
y = 3.7987x + 231.20
R² = 0.7678
r = 0.88
p = 0.001
y = -0.0471x + 6.7007
R² = 0.5493
r = -0.74
p = 0.014
y = -0.0144x + 5.8538
R² = 0.3294
r = -0.57
p = 0.083
Hit point distance from the center of the target (mm)