Biathletes Prefer a Closed-Looped Strategy to Maintain Their Balance During Shooting

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Research Article

Keywords: sample entropy, postural control, internal and external focus, amount of attention

Posted Date: September 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-930009/v1

Abstract

Background: Balance can also be a main factor contributing to success in many disciplines, and biathlon is a representative example. The center of foot pressure (COP) is commonly recorded when evaluating postural control. Because COP measurements are highly irregular and non-stationary, the non-linear deterministic methods are more appropriate for the analysis of COP displacement, such as entropy. The aim of our study was to investigate whether the longitudinal effects of biathlon training can elicit specific changes in postural control.

Methods: 8 national-level biathletes, 15 non-athletes who prior to the experiment took part in 3 months of shooting training, and 15 non-athletes with no prior rifle shooting experience. The data was collected with the use of a force plate. Participants performed three balance tasks in quiet standing, the shooting position (internal focus), and aiming at the target (external focus).

Results: Biathletes obtained significantly lower values of sample entropy compared to the other groups during shooting and aiming to the target trials ($p<0.05$).There were no significant differences in quiet standing trials between all three groups ($p>0.05$). External and internal focuses influenced the process of postural control among participants who had prior rifle shooting experience and the control group: they obtained significantly higher values of sample entropy during shooting and aiming to the target compared to the quiet standing trial ($p<0.05$). The biathletes obtained contrary results. There were no significant differences in the values of sample entropy between three consecutive trials in the ML plane; there was only one significant change in the AP plane. The biathletes obtained significantly lower values of sample entropy in aiming to the target position compared to the quiet standing trial.

Conclusion: Specific balance training is associated with the ability to deal with a more challenging nonspecific task. The biathletes seemed to employ a different motor control strategy than the beginners and control group. They create repeating patterns (more regular signal for COP), which is a vigilant closed-loped strategy to keep one's balance during the shooting and aiming to the target positions.

Background

Coaches in most sports disciplines must face many challenges involving the physical preparation of their athletes. Among them, overloaded calendars and, now more than ever, limited access to sports facilities seem to be especially important. Together, those factors significantly increase the risk of injury (1). Therefore, the proper management of athletes' health should be considered a priority. Developing better postural control can be an effective way to achieve this goal (2). Balance can also be a main factor contributing to success in many disciplines, and biathlon is a representative example (3). The competition is divided into two parts (skiing and shooting), each demanding a specific set of skills. Long-distance skiing requires a significant endurance capacity. Moreover maximal physical effort influences postural balance and rifle stability during aiming (4). To perform well in shooting, an athlete needs to be concentrated, precise, and maintain balance while facing significant physiological stress. Recent studies have shown that elite female and male shooters are characterized by less body sway than non-elite shooters (5–7). Additionally, significant differences in this ability can also be observed between high-level and low-level biathletes (5,8,9). The center of foot pressure (COP) is commonly recorded when evaluating postural control. Because COP measurements are highly irregular and non-stationary, the non-linear deterministic methods are more appropriate for the analysis of COP displacement (10). They allow for the exploration of the randomness or predictability of the COP fluctuations (11,12). One of the frequently-used methods to measure the complexity and regularity of COP signals is entropy (13).

Although entropy has been used to examine the complexity of human postural control over the last two decades, its interpretation is still intangible. In general, entropy describes the regularity of a time series. Regularity quantifies the unpredictability level of the COP fluctuation over time by analyzing the probability of a particular sequence of COP values to repeat itself over time. Low values indicate a more regular signal (higher expertise), and high values are a sign of more chaotic properties of the signal (and pathology/disability) (15,16). This way of interpretation can suggest that the postural control system response to an unexpected perturbation has a specific pattern that can be observed by measuring the entropy of the signal (17–19).

Not all studies support the above interpretation. Some authors have noticed that older people show a higher degree of complexity (higher entropy) compared to adults (13,20,21). This result might reflect impaired sensory systems which fail to provide a precise input for postural control. Taylor et al. (22) similarly noticed that patients with dementia (DP) were characterized by higher values of sample entropy (SampEn) during gait trials.

On the other hand, some results contradict the hypothesized higher degrees of complexity in athletes not only in clinical practice, but also in sports. There are studies that showed no changes in the regularity of COP between a highly-skilled group and a healthy age-matched control group (CG) during a simple balance task (23–25). In turn, Schmit et al. (26) noticed that ballet dancers have decreased entropy compared to runners, even though dancers are considered more proficient in using their balance ability. Additionally, Raffalt et al. (27) showed that rifle shooters had a lower entropy than non-shooters during a single leg stance. With such a broad range of results, is it possible to clearly decide if a higher or lower entropy value can be attributed to postural control efficiency? Rhea et al. (28) suggested that before any conclusions are made, it is necessary to first take a look at the direction of changes and try to find an explanation for those changes.

There is a direct relationship between COP regularity and the amount of attention invested in posture (29). COP regularity decreases when attention is experimentally diverted from posture e.g. by introducing an additional task (21). It is consistent with the “constrained action hypothesis” proposed by Wulf [(2013)], which demonstrates the presence of automatic motor control processes when attention is withdrawn from controlling one’s balance. However, the level of posture automation depends on a type of additional focus. Recent studies have shown that an external focus (EF) is more beneficial for motor performance and learning (including balance) relative to an internal focus (IF) (30).

The aim of the present study was to investigate the regularity of the COP trajectory of biathletes in positions closely related to the sports competition (shooting position – IF and aiming for the target – EF). To examine whether the longitudinal effects of biathlon training can elicit specific changes in postural control, two research groups apart from professional biathletes were recruited: non-athletes, who completed 3 months of shooting training, and a young, healthy CG. Recent studies have shown that in sports where balance training is one of the most important aspects, athletes are characterized by lower postural sway. Therefore, the authors hypothesized that biathletes would show a more regular COP signal compared to other groups. The authors also assumed that an EF will induce the biggest changes in the automaticity of postural control.

Methods

Participants

Thirty-eight healthy, young participants (32 males, 6 females) took part in the experiment. The first group consisted of 8 national-level biathletes. The second was formed by 15 non-athletes who prior to the experiment took part in 3 months of shooting training, including two practice sessions per week (they were called beginners). The CG consisted of 15 non-athletes with no prior rifle experience. A detailed description of all group characteristics is presented in table 1. Participants were excluded if they presented a lower or upper limb injury at the time of the experiment or one month prior. The participants gave a written informed consent for voluntary participation in the study. The study was approved by the Institutional Bioethics Committee.

Experimental procedure

Participants performed three balance tasks. First, they were asked to stand in a comfortable position with their feet approximately at shoulder width distance on a force platform, without focusing their attention on instructions, (QS – quiet standing). Next, they were asked to stand while holding a rifle in a standing shooting position without any fixation point in front of them (SP – Shooting position). In the last trial, participants were given a target at a distance of 5 meters (target size was adjusted for distance) and an additional task of aiming and holding a laser mark inside the target (AT – Aiming to target). The laser pointer was fixed at the end of the rifle’s barrel (fig. 1).

Participants in the CG were instructed before examination about the proper technique for the standing SP i.e., feet slightly wider than hip width, with feet positioned 90 degrees to the target and body weight evenly distributed on both legs. To provide a stable rifle position, participants were instructed to align the position of hip and elbow to be directly under the rifle.

Each trial lasted 30 seconds and was repeated three times. The order of the trials was randomized for each participant.

Data analysis

The data was registered with the use of the AMTI BP-600900 force platform and AMTI Netforce software. The sampling frequency was set to 50 Hz. The first step of data processing included the low-pass filtering of each measurement using a 4th order Butterworth filter with a cut-off frequency of 7 Hz. The next step involved calculating the center of pressure, which constituted the basis for the evaluation of SampEn of the signal. This method is defined as the probability that two similar sequences will remain similar at the next data point (excluding self matches). The length of the sequences to be compared and the tolerance value until which samples are considered to be similar are specified by the researcher. Calculations were based on the method described by Richman Moorman (2000) (31) using the following formula (e.g. 1):

$$Sample\ Entropy(m, r, N) = -\log\left(\frac{A(r)}{B(r)}\right) \qquad (1)$$

Where *m* represents the number of data points to compare in a sequence, *r* represents tolerance, and *N* represents the length of data sequence. *A(r)* and *B(r)* stand for total number of concordant sequences according to the level of tolerance r in the appropriate dimensional space. The outcome of this calculation varies between 0 (perfectly predictable) and 2 (totally unpredictable) (32). The values of the input parameters in this experiment were based on the results of Ramdani et al. (12). Template vector length (m) was set to 3, and tolerance (r) to 0.2. All data processing was performed using Python (Python Software Foundation. Python Language Reference, version 3.7. Available at http://www.python.org).

Statistical analysis

Before conducting statistical analyses, repeated measurements from each trial were averaged across all participants. Then normality of the data distribution was confirmed by the Shapiro-Wilk test. The homogeneity of the variances between groups was evaluated with Levene's test, and within participants' groups by Mauchly's test of sphericity. To evaluate the effect of group and task on SampEn, a two-way mixed-design ANOVA with group (between participants) and task (within participants) as independent factors was applied to the dependent variable in each direction (AP – Anterior posterior, ML – Medio lateral). In case of an overall effect of a group or task or interaction between two factors, pairwise t-test comparisons with Bonferroni corrections were applied. As a means of measuring effect size, generalized eta square statistics were used (33). Effect sizes were evaluated as small (0.1-0.3), medium (0.3-0.5), and large (above 0.5) based on guidelines described by Cohen [3]. The level of significance was set to 0.05. All statistical analyses were performed in R (R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/).

Results

A-P direction

There were statistically significant interactions between the experimental groups and conditions, $F(4, 70)=9.909$, $p<0.05$, $\eta_G^2=0.174$. Considering the Bonferroni adjusted p-value, the simple main effect of group was significant for SP ($p<0.05$, $\eta_G^2=0.414$) and AT conditions ($p< 0.05$, $\eta_G^2 = 0.579$). There was no difference between groups in QS. Pairwise comparisons showed that the mean SampEn value was significantly different in SP between the CG and biathletes, and between beginners and biathletes $p<0.05$. The same pattern was observed in the AT condition. There was significant difference between the CG and biathletes, and between beginners and biathletes, $p<0.05$. In both trials there was no difference between controls and beginners.

Within group comparisons indicated the significant effect of experimental conditions on the SampEn in all groups. The most significant differences were observed in the CG ($p<0.05$, $\eta_G^2=0.366$), followed by the beginners group ($p<0.05$, $\eta_G^2=0.267$), and least significant in the biathletes group ($p<0.05$, $\eta_G^2=0.155$). As expected, pairwise comparisons showed that in the CG the SampEn differed significantly in SP and AT compared to QS, $p<0.05$, respectively but no difference was observed between SP and AT trials, $p=0.14$. Similarly, in the beginners group the SampEn was significantly different in SP and AT compared to QS, $p<0.05$ in both situations, but no differences were observed between SP and AT conditions. In the biathletes group, the changes between consecutive trials were much smaller and, contrary to both other groups' values in the SP and AT trials, were lower than in the QS condition. No significant change in SampEn was observed between QS and SP. In addition, there was no difference between SP and AT. The only significant difference for this group was observed between QS and AT trials, $p=0.04$ (fig. 2).

M-L direction

Similar to the AP plane, there were statistically significant interactions between experimental groups and conditions, $F(4, 70)=4.525$, $p<0.05$, $\eta_G^2=0.131$. Considering the Bonferroni adjusted p-value, the simple main effect of the group was significant for the SP ($p<0.05$, $\eta_G^2=0.479$) and AT conditions ($p<0.05$, $\eta_G^2=0.495$). In addition, here no difference in the QS condition was observed. Pairwise comparisons show that the mean SampEn value was significantly different in SP between the CG and biathletes, and between beginners and biathletes $p<0.05$. The same pattern was observed as in the AT condition. There was a significant difference between the CG and biathletes, and between beginners and biathletes, $p<0.05$. In both trials, there was no difference between the control and beginner groups.

Within group comparisons only showed the significant effect of experimental conditions on the control and beginner groups. Most significant differences were observed in the beginners group ($p<0.05$, $\eta_G^2=0.318$), followed by the CG ($p<0.05$, $\eta_G^2=0.225$), and no significant effect was observed for biathletes ($p=0.31$, $\eta_G^2=0.061$). In the CG only a significant difference in the ML direction was observed between the QS and AT conditions, $p<0.05$. However, in the beginners group changes were similar to the AP direction with significant differences observed between QS and SP $p<0.05$, and between the QS and AT conditions $p<0.05$ (fig.3).

Discussion

The aim of the present study was to investigate whether an internal and external focus of attention could promote greater postural stability. Also, we wished to explore how the process of postural control differs between groups of different levels of expertise.

In the present study there were no significant differences in the regularity of COP between three research groups during QS in both the AP and ML planes. This result is in line with other studies investigating the regularity of COP among athletes in trials which included a dual task condition (23), a more specific posture like a ballet position (24), or more demanding balance conditions like eyes closed or an unstable surface (25). In all mentioned works, the experimental conditions led to an increase in entropy among athletes compared to the CG. Maintaining an upright body posture is quite easy for all healthy participants. Therefore, we assumed that professional sports training does not transfer balance improvements to simple motor tasks or QS does not require “elite level” balance.

Biathletes were characterized by lower values of entropy, especially during the SP and AT trials and both in the AP and ML plane, compared to the other two groups, which confirms our first research hypothesis. This result stands in contrast with the research cited above, where an additional or more demanding balance task led to a decrease in COP regularity among athletes. However, we must consider a few important aspects of this examination. First, we cannot ignore the fact that for professional biathletes, SP and AT trials are a familiar position. Years of professional training made it more automatic and required less attentional resources. Therefore, additional tasks should not interfere significantly (or at least significantly less than not trained groups) with the main motor task. This claim corresponds well with Fitts’s *Motor Learning Theory* (34). According to the theory, after many years of sports training, biathletes reached the third (autonomous) stage of motor learning. It can be also observed in our results, specifically in the increased regularity of the COP signal during AT trials compared to QS and SP in the AP plane, as well as no significant changes between trials in ML plane. These outcomes are contrary to the CG and BG results, which are in line with the “*constrained action hypothesis*.” Introducing an internal and external focus led to a decrease in COP regularity in both groups. However, there were no differences between SP and AT trials. Therefore, the two types of additional focus included in this research triggered the same changes in COP structure, which does not confirm our second research hypothesis. However, there is strong evidence that biathletes present different postural control strategies, which ensures motor success.

To achieve good results, elite biathletes aim at decreasing postural and rifle sway in the SP (5). Performing a shot as soon as a stable position is obtained is a crucial factor for success (35). Efforts put towards following this strategy can be observed in the experimental data. Postural sway and the regularity irregularity of the COP signal tend to be positively correlated (36). This was also confirmed by research by Raffalt et al., who observed that sport rifle shooters are characterized by a higher regularity of the COP signal and lower body sway compared to non-shooters during single-legged standing. The same pattern of changes in the measured data can be also observed in our research; biathletes were characterized by a significantly more regular COP signal in positions closely related to their competition.

When competing, biathletes perform in quasi constant conditions. They use the same sportswear as during their training, the target is at a familiar distance, and they shoot only after they adjust to the environmental conditions and when they can stabilize their posture. From this perspective, we can say that biathletes’ posture is controlled mostly in a close-loop pattern even though shooting is a single short non-cyclic movement. In our study, it is even more clear in SP and especially during AT conditions as aiming was not followed by a shot. A main goal in order to achieve success in shooting is to minimize the movements of the gun barrel. This, however, requires a high level of postural stability (7). In addition, movement variability in a performed task diminishes in the process of professional training (37). Therefore, we can also expect that in experimental conditions biathletes will perform significantly better in this aspect compared to other groups. In the present study, as expected, biathletes were characterized by significantly lower values of SampEn during AT compared to QS. We can therefore conclude that their level of proficiency is reflected to some extent in our data. Another conclusion could be that well-developed postural control mechanisms can play a significant role in achieving success in a competition.

Based on the current research, Biathletes are characterized by more regular signal of COP. This means that they have more predictable, repetitive pattern of postural control. It is speculative whether to introduce additional disturbing external factors into the training regimen in order to push the limit a little further. There is a chance that the athlete, knocked out of the comfort zone, will perform worse due to the disturbance in their repetitive and known patterns. It seems to be enough that they have to deal with fatigue and changing weather conditions. Other aspects influencing the final result, like e.g. size of the aim, distance to target, shooting equipment and position, are constant. In our opinion one the aims of the training is to develop a postural control pattern, that ensures their sports success and overstimulation might decrease accuracy in shooting. For sure, we can monitor the progress by observing the changes in signal entropy over time, for example during training program which provides valuable information of athletes progress.

This study does present a few limitations. The main one would be that biathletes begin shooting in a heavily fatigued state after covering a certain cross-country distance. In our research, they performed a balance examination at full rest. Secondly, during their competition biathletes perform a shot after acquiring a good position, when in our study they had to stay in a position concentrated on the target for the desired time. Lastly, our results for the beginners group were closely related to the CG, which can suggest that three months of training is not sufficient for inducing changes in the postural control system.

Conclusion

The results of the present study suggest that specific balance training is associated with the ability to deal with a more challenging nonspecific task such as SP and AT. Furthermore, biathletes seem to employ a different motor control strategy than beginners and participants in the CG. Among biathletes, the variability of the COP signal was significantly lower than in the other groups. For this group it contributes to a more stable posture, which is essential for a successful shot. Our results do not support the theory connecting lower values of SampEn with poor balance or postural control deficiency.

Abbreviations

COP: center of foot pressure, EF: external focus, IF: internal focus, CG: control group, SampEn: sample entropy, QS: quiet standing, SP: shooting position, AT: aiming to target

Declarations

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

Conception: GJ, DG, design of the work: RZ, KSZ; acquisition, analysis: JM, RZ, interpretation of data: JM, RF, drafted the work: JM,KS; substantively revised: GJ, KS

Availability of data and materials:

Data are available from corresponding authors upon request.

Ethics approval and consent to participate

The all experimental protocols were approved by The Jerzy Kukuczka Academy of Physical Education Bioethics Committee in Katowice, Poland, consent number 7/2013/3/00953. The study was conducted in accordance with the Declaration of Helsinki. The study participation was voluntary. A participant was able to withdraw consent at any time without stating the reason and without any individual disadvantage. Their approval was documented via their signature on the informed consent forms. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Written informed consent was obtained from the participants for publication

of their individual details.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Characteristics of experimental groups

	Control	Beginners	Biathlon
N	15	15	8
Age [years]	21.2 ± 0.8	22.3 ± 0.6	26.1 ± 5
Height [cm]	180.5 ± 7.8	179.6 ± 6.5	170.6 ± 9.5
Weight [kg]	74.8 ± 9.5	73.9 ± 8.8	58.9 ± 11.5

Figures

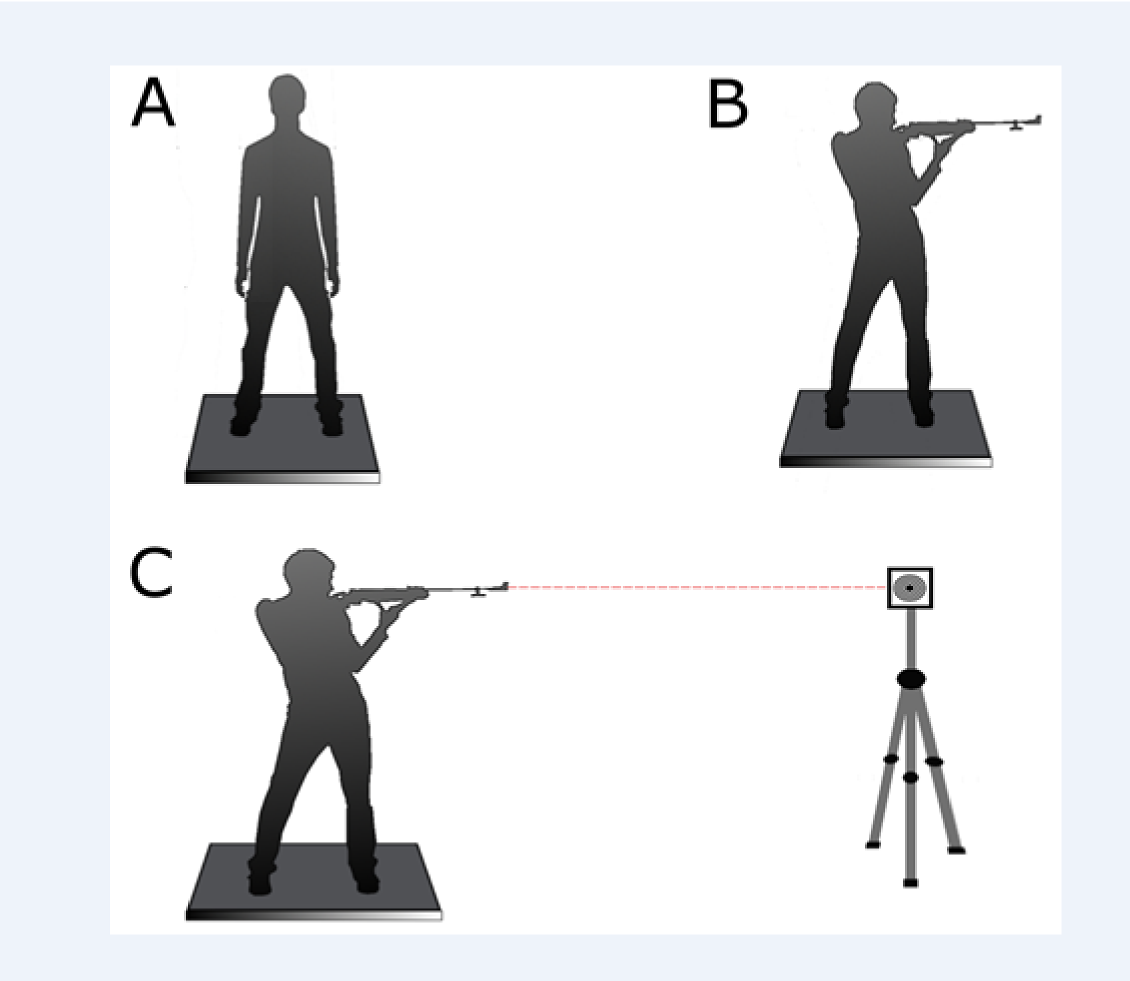

Figure 1

Experimental procedure. Legend: A – quiet standing; B – shooting position; C – aiming to target

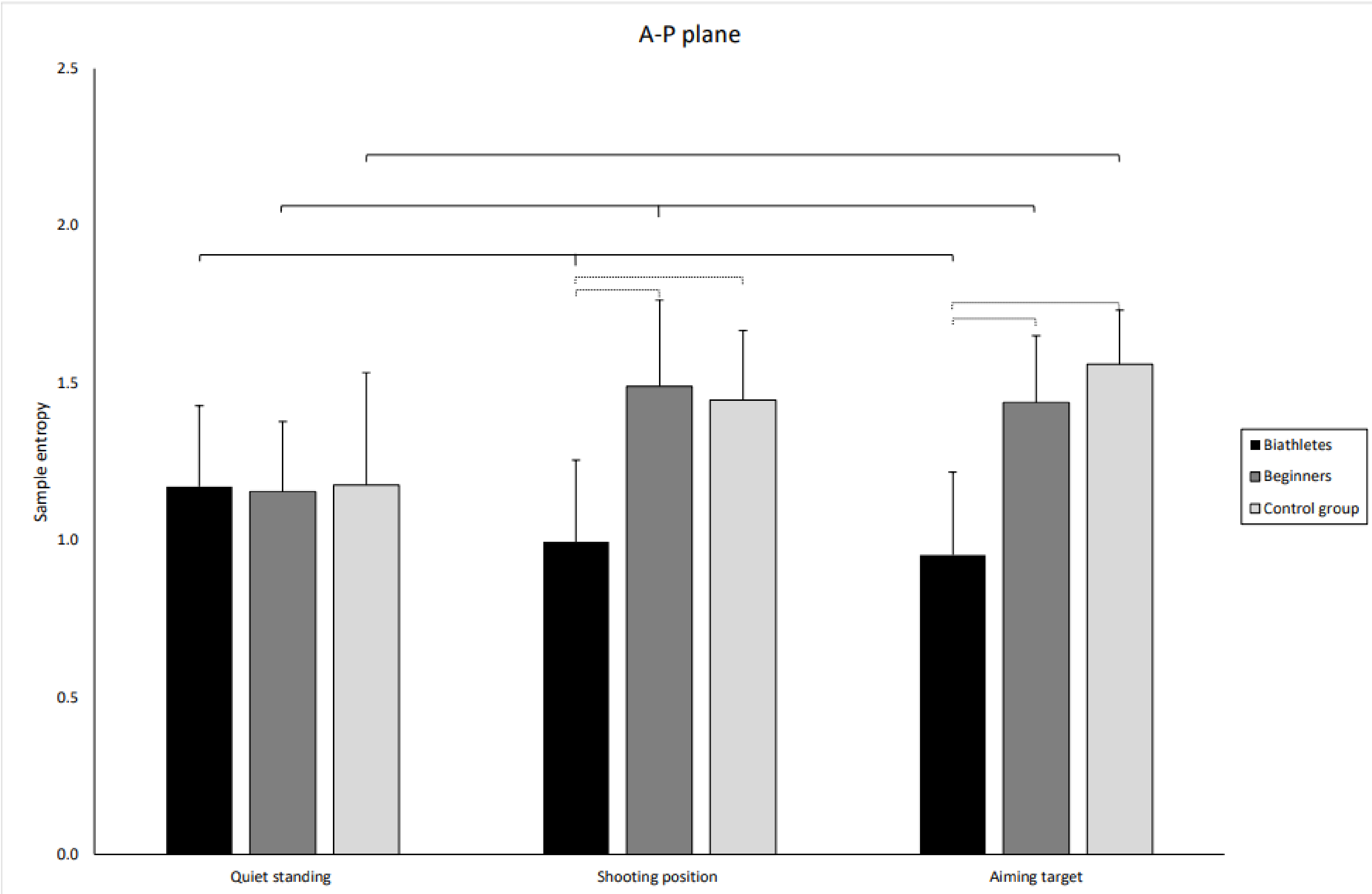

Figure 2

The mean values of SampEn in the anterior-posterior direction (standard deviations marked as error bars) in the biathletes, beginners and control group.

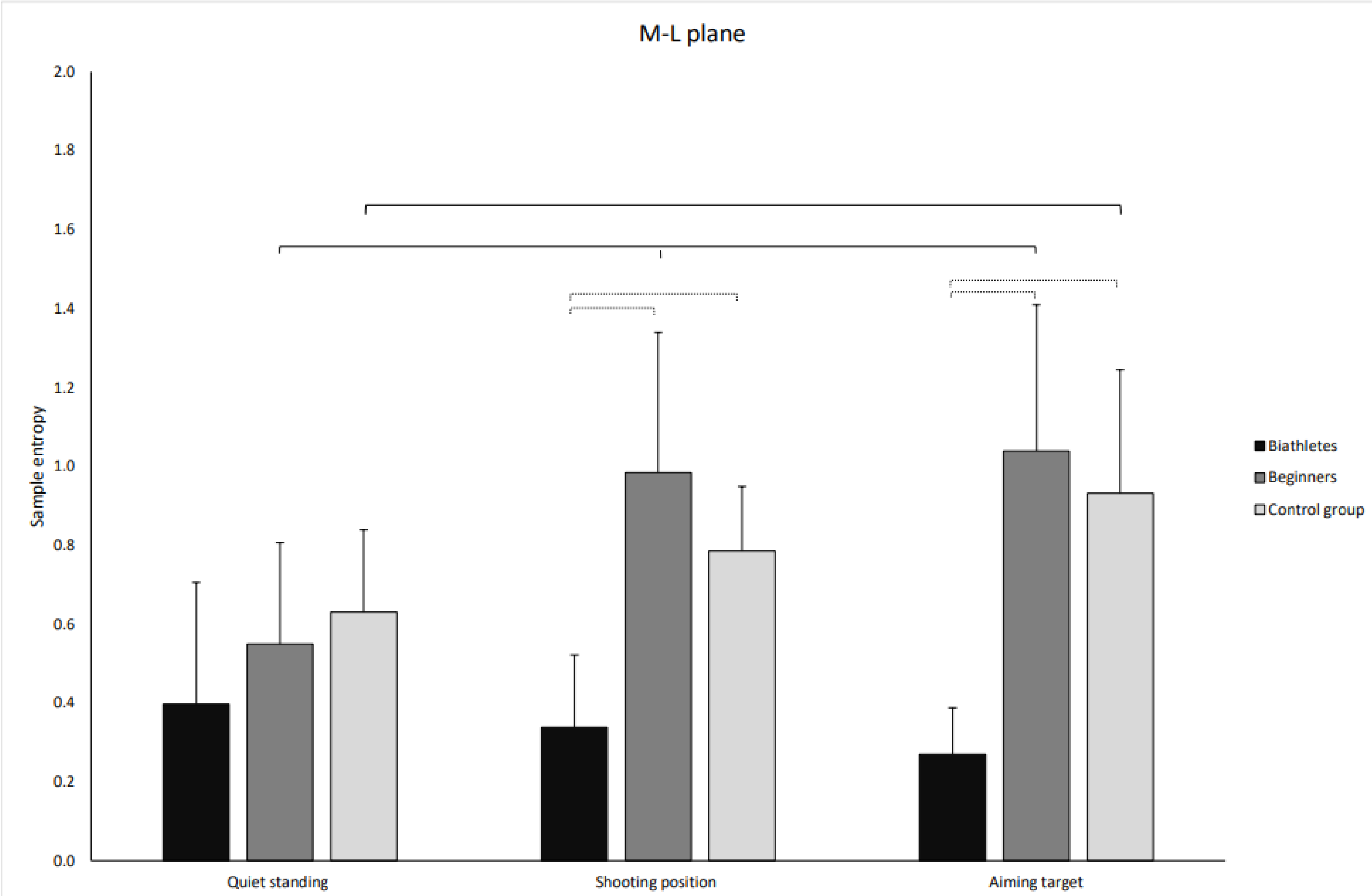

Figure 3

The mean values of SampEn in the medio-lateral direction (standard deviations marked as error bars) in the biathletes, beginners and control group.