The Effect of Expertise on Postural Control in Elite ju-jitsu Athletes

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Abstract

Background: The testing of athletes in ecological conditions is based on the concept that sport-specific adaptations in postural control are observed mostly in positions or tasks that are related to the practice of a specific movement. Due to the high postural control demands of ju-jitsu, it is likely that long-term ju-jitsu training may influence the process of maintaining a stable posture, especially in positions directly related to combat. The purpose of this study was to examine the postural sway characteristics of elite ju-jitsu athletes in ecological and non-ecological conditions with an approach not previously used in martial arts.

Methods: The study was conducted on eleven male elite ju-jitsu athletes and ten non-athletes. The data was collected with the use of a force plate under two conditions: quiet standing and ju-jitsu combat stance. Apart from the standard analysis of the spatial-temporal parameters of COP, sensitive methods in COP data processing were used, namely rambling-trembling and sample entropy. The non-parametric U Mann-Whitney test was used to compare both positions.

Results: The main findings of the study showed that in quiet standing, elite ju-jitsu athletes and non-athletes had comparable postural control in both the anterior-posterior and mediolateral planes. In contrast, elite athletes had lower values of postural sway and higher values of sample entropy in comparison to the non-trainees in the combat stance ($p<0.05$). The rambling-trembling decomposition of the COP data did not exhibit additional differences between groups beyond the standard analysis.

Conclusions: Our results confirmed the importance of a sport-specific environment in investigating the subtle differences in the postural regulation of elite athletes. The sample entropy results indicated more irregular characteristics of postural sway in the elite ju-jitsu athletes, representing more automated postural control.

Background

Ju-jitsu is a high-intensity, modern martial art that combines both karate and judo techniques (1). In particular, ju-jitsu fights proceed in three stages: (1) punches and kicks to the head and torso, (2) throwing, choking, and joint locking, and (3) floor techniques, when the competitors are kneeling, sitting, or lying on the mat. Although the floor techniques are allowed, whenever the fight is stopped by the referee, it is renewed in the standing position (2). Therefore, one of the aims during a fight is to disturb the opponent's balance while gripping the uniform or forcefully throwing or pushing. Maintaining stable posture is also challenging in defensive and counterattacking techniques performed in highly unstable positions (3). Considering the above, postural control seems to be one of the most important factors determining the effectiveness of a ju-jitsu athlete. However, interest in postural control in ju-jitsu was found to be surprisingly marginal when compared to other martial arts.

Many studies have shown that training in martial arts improves postural control in patients with neurological disorders (4), the visually impaired (5), and healthy adults alike (6). Changes in postural control are also observed as a result of long-term combat sports training in judo (7), karate (8), taekwondo (9), or wrestling athletes (10). Generally, the elite senior athletes show superior balance measured in static and dynamic tests in comparison to untrained individuals and junior athletes (11). In particular, elite judokas are characterized by a smaller radius of center of foot pressure (COP) and recovered their balance significantly faster after kicking (11). Differences in postural stability were also observed in the early years of training, with adolescent martial arts practitioners showing a superior balance ability in comparison to their psychically active peers (12).

However, in many cases differences in postural control between athletes of different levels of expertise or between trained and untrained athletes were not observed. It has been proposed that changes in postural control might be observed in ecological contexts, i.e. sport-specific positions or environments (13), but not in non-ecological ones, unless the task reaches the desired level of difficulty or is sufficiently specific (14). For example, in static conditions, i.e. quiet standing, elite judokas, dancers, and surfers did not exhibit better postural stability than their intermediate peers (15–17). However, it was possible to differentiate them while performing a dynamic postural task on an unstable surface (surfers) or in dance-like positions (dancers).

Testing athletes in ecological conditions is based on the concept that sport-specific adaptations in postural control are observed mostly in positions or tasks that are related to the practice of specific movements (18–20). This assumption was confirmed in the study by Paillard (20), which compares the postural stability of judokas who practice their favorite throwing technique in a monopedal and bipedal stance. The results showed that in the assessment of double leg support, judokas who practice throwing in a bipedal stance were more stable than those who trained in a monopedal stance, and conversely, in the assessment of single leg support, superior balance was found in judokas who train in the single-leg support. Similar results have been observed by Casabona et al. (18), who analyzed COP in stances with different foot configurations in ballet dancers. Differences between the experts and control group were only found in the stance in which the foot configuration matched the needs of ballet's practice. However, it is worth mentioning that there are several studies in which the differences in postural control between martial art athletes and healthy control subjects were observed in non-specific tasks, i.e. quiet standing (10, 21, 22) and functional tests (21).

In addition to the specificity of movement and environment, more sensitive methods of COP signal analysis may also be used to distinguish the differences in postural control between subjects. One of these methods is sample entropy (SampEn), which quantifies the regularity of a time series and is commonly used as a measure for the automatization of the postural control process (23). Commonly, larger entropy values indicate lower regularity in the COP signal, and as a consequence the more automatization in postural control (24). On the other hand, low values of entropy show high regularity of the signal and are associated with high participation of attention in the process of maintaining a stable posture.

The second method for analyzing the dynamic structure of COP was proposed by Zatsiorsky and Duarte (25). It is based on the decomposition of stabilograms into two components – rambling and trembling.

While rambling “reveals the motion of a moving reference point with respect to which the body's equilibrium is instantly maintained,” the trembling component “reflects body oscillation around the reference point trajectory” (25).

Considering all the above, in the present study we would like to assess the differences in postural control between elite ju-jitsu practitioners and untrained control subjects in non-ecological conditions (quiet standing) and ecological conditions (combat stance) using sensitive methods of signal analysis (sample entropy and rambling-trembling). We hypothesize that there will not be any differences between ju-jitsu athletes and control subjects in the standard parameters of COP during quiet standing. However, the differences between athletes and control subjects will be observed in the sport-specific combat position. Additionally, we suppose that the use of rambling-trembling will help to detect subtle differences between groups which could not be found using standard analysis. Finally, we hypothesize that elite athletes will be characterized by more automated postural control in the combat stance when compared to control subjects, which will be observed in higher values of sample entropy.

Materials And Methods

Participants

Twenty-one healthy male participants took part in the study (Table 1). The participants were divided into two groups: elite ju-jitsu athletes (members of the Polish National Team, Europe and World Championship medalists with 7 to 12 years of training experience) and the control group. The control group consisted of physical education students who were not involved in any sport at a competitive level. The Institutional Bioethics Committee approved the study and all procedures conformed to the Declaration of Helsinki.

Table 1
Characteristics of the examined groups.

	N	Sex	Age (mean ± SD) [years]	Height (mean ± SD) [cm]	Weight (mean ± SD) [kg]
Ju-jitsu	11	M	17 ± 1.5	178 ± 5.2	62 ± 19.6
Control	10	M	22 ± 1	179 ± 4.9	80 ± 10.4

Study Design

To assess postural stability, we used the force plate (AMTI, AccuGait, Watertown, MA, USA) by which the ground reaction forces and moments of forces were registered at a 100 Hz sampling frequency.

The experimental procedure included measurements in two types of stances: (1) quiet standing (QS), during which the participants were standing barefoot on the force plate with their arms along the torso (Figure 1A), and (2) the combat stance (CS) which was characteristic for the initial ju-jitsu stance during combat (Figure 1B). In CS, the participants stood with their feet shoulder-width apart with one of the foot in front. The bodyweight was equally distributed among both legs. The arms were extended in direction of the “opponent” with the hands situated at chest level. The hips were bent, thus the torso and thighs were at an angle of approximately 90 degrees. As a result, the torso was strongly tilted forward.

In both QS and CS trials, the participants were instructed to maintain a stable posture with their gaze fixated at a reference point located 3 m away in front of them at eye level. The QS and CS trials were repeated 3 times and lasted for 30 seconds each.

Data processing

The raw data from the force plate was processed offline using Matlab r2020b software (Mathworks Inc., Natick, MA, USA) with a 7 Hz, fourth-order, low-pass Butterworth filter. The following 3 subsets of posturographic data in the anterior-posterior (AP) and mediolateral (ML) directions were extracted:

(1) Spatio-temporal measures of COP: (a) range of COP (raCOP) [cm] – maximum excursion of the COP in a given direction, (b) velocity of COP (vCOP) [cm/s] – ratio of the total length of the COP trajectory and the recording time length, (c) root mean square of COP (rmsCOP) [cm] – the displacements of the COP around the mean COP.
(2) Rambling-trembling decomposition of COP: Zatsiorsky and Duarte’s (25) method for COP decomposition was used to obtain the rambling (raRAMB, vRAMB, rmsRAMB) and trembling (raTREMB, vTREMB, rmsTREMB) components of the variables listed above.
(3) Sample entropy measures of COP: The SampEn is the negative logarithm of the probability that a data set of length N, having repeated itself for m samples within a tolerance r, will also repeat itself for m + 1 samples, without allowing self-matches. The parameters m and r must be fixed for each calculation; m is the length of sequences to be compared, and r is the tolerance for accepting matches. To select the input parameters of the algorithm we used the criterion proposed by Richman and Moorman (26) and Lake et al. (27): $m = 3$ and $r = 0.2$ x the standard deviation of the data set.

Statistics

The Shapiro-Wilk test was used to check the data for normal distribution, while variance homogeneity was investigated with Levene’s test. In order to compare the QS and CS variables independently between the groups, the non-parametric U Mann-Whitney test was used. The level of statistical significance was adopted for the value of $p < 0.05$. Statistical analyses were performed using Statistica v.13.3 (TIBCO Software Inc.).

Results

Comparison of elite ju-jitsu athletes and control subjects in QS

No significant differences between groups were observed in the spatio-temporal parameters of COP, rambling-trembling, and sample entropy in QS (Figures 2 and 3).

Comparison of elite ju-jitsu athletes and control subjects in the CS

Elite ju-jitsu athletes showed a smaller body sway than control subjects in AP, which could be observed in the spatio-temporal parameters of COP: raCOP ($U = 13$, $n_1 = 11$, $n_2 = 10$, $p < 0.01$) and rmsCOP ($U = 9$, $n_1 = 11$, $n_2 = 10$, $p < 0.01$) (Figure 4 AP), as well as in the rambling parameters: raRAMB ($U = 2$, $n_1 = 11$, $n_2 = 10$, $p < 0.01$) and rmsRAMB ($U = 9$, $n_1 = 11$, $n_2 = 10$, $p < 0.01$) (Figure 4 AP). No significant differences between groups were found in COP velocity, rambling, and trembling.

The ju-jitsu athletes presented higher values of SampEn in the combat stance in the AP ($U = 17$, $n_1 = 11$, $n_2 = 10$, $p < 0.01$) and ML ($U = 26$, $n_1 = 11$, $n_2 = 10$, $p = 0.04$) (Figure 5).

Discussion

The aim of the present study was to assess the differences in postural control between elite ju-jitsu athletes and untrained control subjects in non-ecological and ecological conditions using sensitive methods of signal analysis.

The results confirmed the hypothesis that no differences will be found in postural control when the task was not sufficiently specific, i.e. it did not involve the context in which the athletes are trained. These results are in line with previous findings which investigated the effect of expertise on the non-ecological context of postural control (static balance) among judokas, surfers, and dancers (15–18). Moreover, the differences between elite ju-jitsu athletes and controls were observed in the so-called ecological conditions introduced in the present study as the ju-jitsu CS. This supports the idea that the nature of long-term sports practice leads to the acquisition of specific postural regulations presented in sport-specific positions and environments (see Introduction). The superior postural performance in ju-jitsu athletes in the CS was characterized as the ability to minimize postural sway. This was observed in lower values of COP range and rms. Many previous reports associated smaller postural sway with better postural skills (17, 18, 28–31). For example, ballet dancers exhibited lower values of COP area, range, and rms than non-dancers in a feet configuration represented the ballet-specific position (18). Similarly, significant differences between elite dancers and control subjects were majorly found in dance-like techniques, which required weight transfer on the ball of the foot, on an unstable surface, with and without vision, and in ballet jumps, followed by maintaining the new, stable posture (17). In the study by Gauchard et al. (32), reduced body sway was observed in karatekas when compared to control subjects, especially in more challenging conditions, i.e. standing with eyes closed on a foam surface.

The greater precision of postural control in elite ju-jitsu athletes may correspond to the contribution of sensory-motor pathways (proprioceptive, vestibular and visual) in balance control during the combat stance. It is generally accepted that repetitive practice of motor tasks in a sport-specific environment results in neurological adaptations which involve the increased exploitation of some sensory inputs at the expense of the others. For example, athletes who train on an unstable surface, i.e. a soft mat such as wrestlers, were found to be proprioception-dependent, while boxers who compete on a stable surface relayed visual information to a greater extent (33). Similarly, judokas exhibited better postural performance than ballet dancers in conditions with eyes closed in comparison to eyes opened. In fact, judokas train in a constantly changing environment due to their opponents' actions, therefore giving greater importance to proprioceptive and vestibular information (7). However, to confirm how the discussed sensory pathways influence postural regulation in elite ju-jitsu athletes, the methodological approach should include attempts with eyes closed. The lack of this data can be considered as one of the limitations of the present study.

In contrast, another interpretation of postural sway has been introduced. Some authors have proposed that sports expertise leads to redundancy in the sensorimotor system, which is based on specific adaptations at the spinal and supraspinal level. This redundancy may be observed in increased values of COP range, and as a consequence increased body sway in elite athletes. Indeed, larger postural sway was found in studies investigating postural regulation in martial arts athletes, such as wrestlers or karatekas (10, 21, 22), and may others, such as biathlonists, runners, or cyclists (13). Therefore, the interpretation of the postural sway of elite athletes is not straightforward and should be done in accordance to the context of the study. We believe that considering the reduced postural sway of ju-jitsu athletes in the CS as a poor balance ability would be inappropriate and misleading.

In our study, the rambling-trembling signal decomposition did not show any additional differences in postural control between ju-jitsu athletes and the control group in both QS and CS when compared to standard COP analysis. As a consequence, the results did not support our hypothesis that this more sophisticated method would reveal further subtle differences in postural control between the examined groups. These results are surprising, since many previous reports evaluating postural control in dancers (34), karatekas (21, 22), wrestlers (10), children (35), or older adults (36) benefited from signal decomposition.

Although expected, interesting results were found in the sample entropy values. More specifically, no significant differences between groups were found in QS, while in the CS elite ju-jitsu athletes were characterized by significantly higher values of sample entropy when compared to control subjects. According to Borg and Laxaback (23), the high entropy and chaotic excursion of COP can be interpreted as a sign of a healthy, vigilant system, but also as an effective strategy to maintain body balance. What is more, according to Donker et al. (37), sway regularity was also found to be positively correlated with the amount of attention invested in postural control. In another words, the more irregular the signal is, the less attention is devoted to balance control. Based on our results, it appears that when elite ju-jitsu athletes set the initial CS, posture control is mainly handled on "auto-pilot," so that a greater amount of attention is allocated to observe and analyze the behavior of the opponent. This explanation is in strong agreement with the recent study of Rhea et al. (38), which emphasized that the external focus of attention can be used to increase postural control entropy in young and older adults.

The automatization of postural control in elite athletes was discussed in the study by Kuczyński et al. (39) investigating the effect of dual tasking on postural control in dancers. According to the authors, elite dancers were able to act at the same level of effectiveness in dual tasking (postural task combined with mental task), while non-athletes could not devote the desired level of attention to postural control, and as a consequence presented worse stability. It has been proposed that the automation of postural control in dancers was associated with the environment in which they perform. Dancers must invest much attention in fast decision-making concerning their body position and direction of movement in space, and in many situations anticipate the position of their partners. If that is the case, it is not surprising that martial arts athletes present more automated postural control than their non-trained peers.

To the best of our knowledge, this is the first study which examines postural control in elite ju-jitsu athletes. This is not a trivial act as various kinds of ju-jitsu are some of the fastest-growing martial arts in the world. At the same time, ju-jitsu is one of the few martial arts which is not sufficiently described in the literature in terms of postural control. Apart from the strengths, a number of potential limitations should be considered. The first limitation, as discussed earlier, was not including trials with eyes closed. Therefore, postural strategies corresponding to the preferential involvement of sensory-motor pathways could not be addressed. The second limitation was the age differences between the athletes and control subjects. Although all ju-jitsu athletes included in the study were post-PHV (peak height velocity), the research should be repeated for a group of subjects with similar ages.

Conclusion

In non-ecological conditions (quiet standing), elite ju-jitsu athletes and non-athletes had comparable postural control in both the anterior-posterior and mediolateral planes. However, the superior ability of ju-jitsu athletes to control their body posture was found in ecological conditions (combat stance) and was characterized by reduced body sway and greater automation observed in higher values of sample entropy. The rambling-trembling decomposition did not exhibit any additional differences in postural control between athletes and non-athletes, showing results similar to standard COP analysis.

Abbreviations

QS – quite standing

CS – combat stance

COP – center of foot pressure

raCOP – maximum excursion of the COP in a given direction

vCOP - ratio of the total length of the COP trajectory and the recording time length

rmsCOP - the displacements of the COP around the mean COP raRAMB, vRAMB, rmsRAMB – rambling of spatio-temporal measures of COP

raTREMB, vTREMB, rmsTREMB - trembling of spatio-temporal measures of COP

SampEn – sample entropy

Declarations

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Authors’ contributions

Conception: MR, KS, design of the work: SD, KS, MR; acquisition, analysis: KW, PK, WM, interpretation of data: AA, MR, WM, drafted the work: AA, WM ; substantively revised: WC

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 University of Rzeszów. 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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Figures

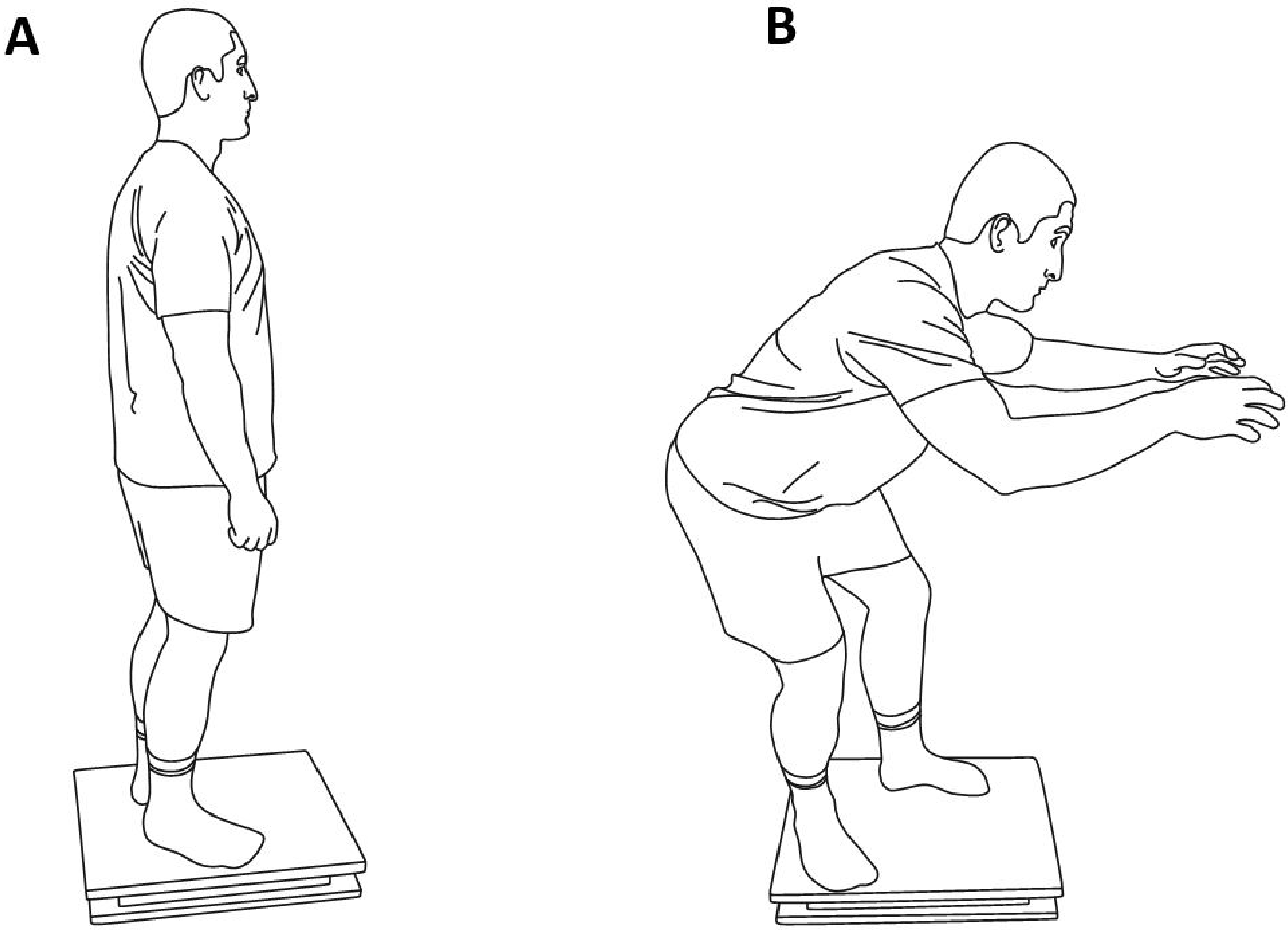

Figure 1

Two experimental conditions: (A) quiet standing and (B) ju-jitsu combat stance.

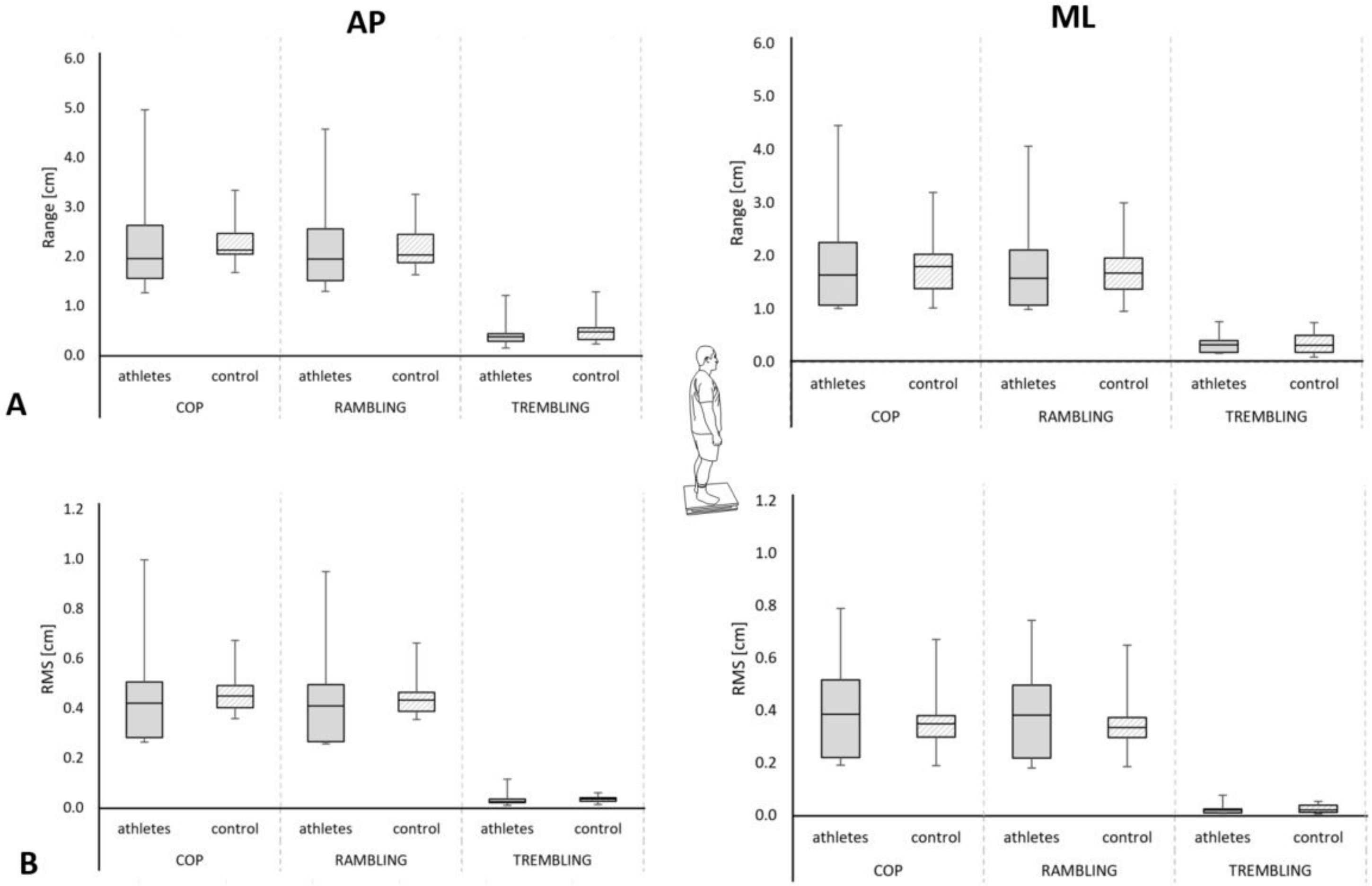

Figure 2

Comparison between groups in quite standing. Legend: (A) range of COP, rambling, and trembling, and (B) root mean square (RMS), rambling, and trembling in the anterior-posterior (AP) and mediolateral (ML) directions (median, upper, and lower quartile, min. and max. marked as error bars) (*p < 0.05).

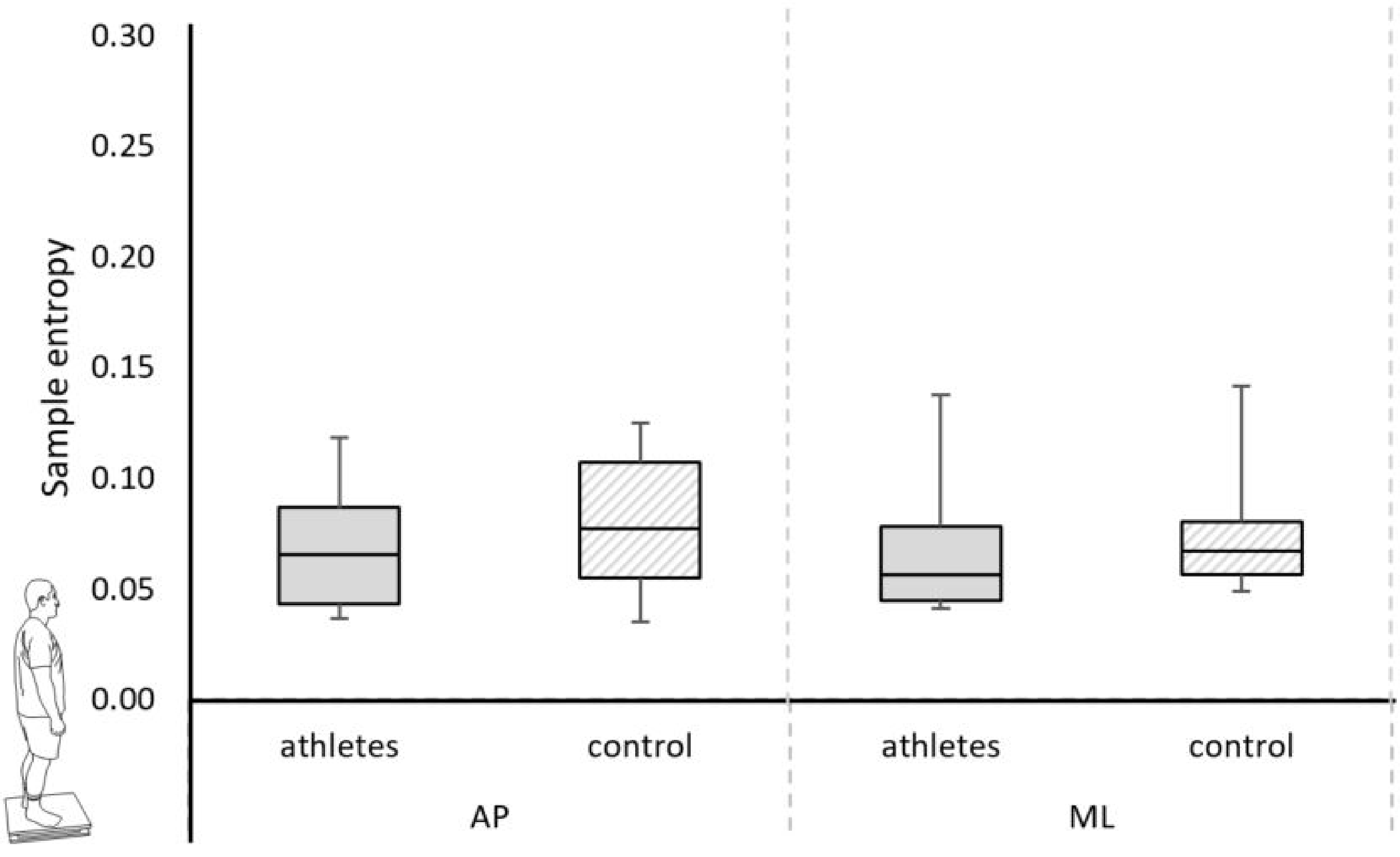

Figure 3

Comparison between groups of the sample entropy in quite standing. Legend: anterior-posterior (AP) and mediolateral (ML) directions (median, upper, and lower quartile, min. and max. marked as error bars) (*p < 0.05).

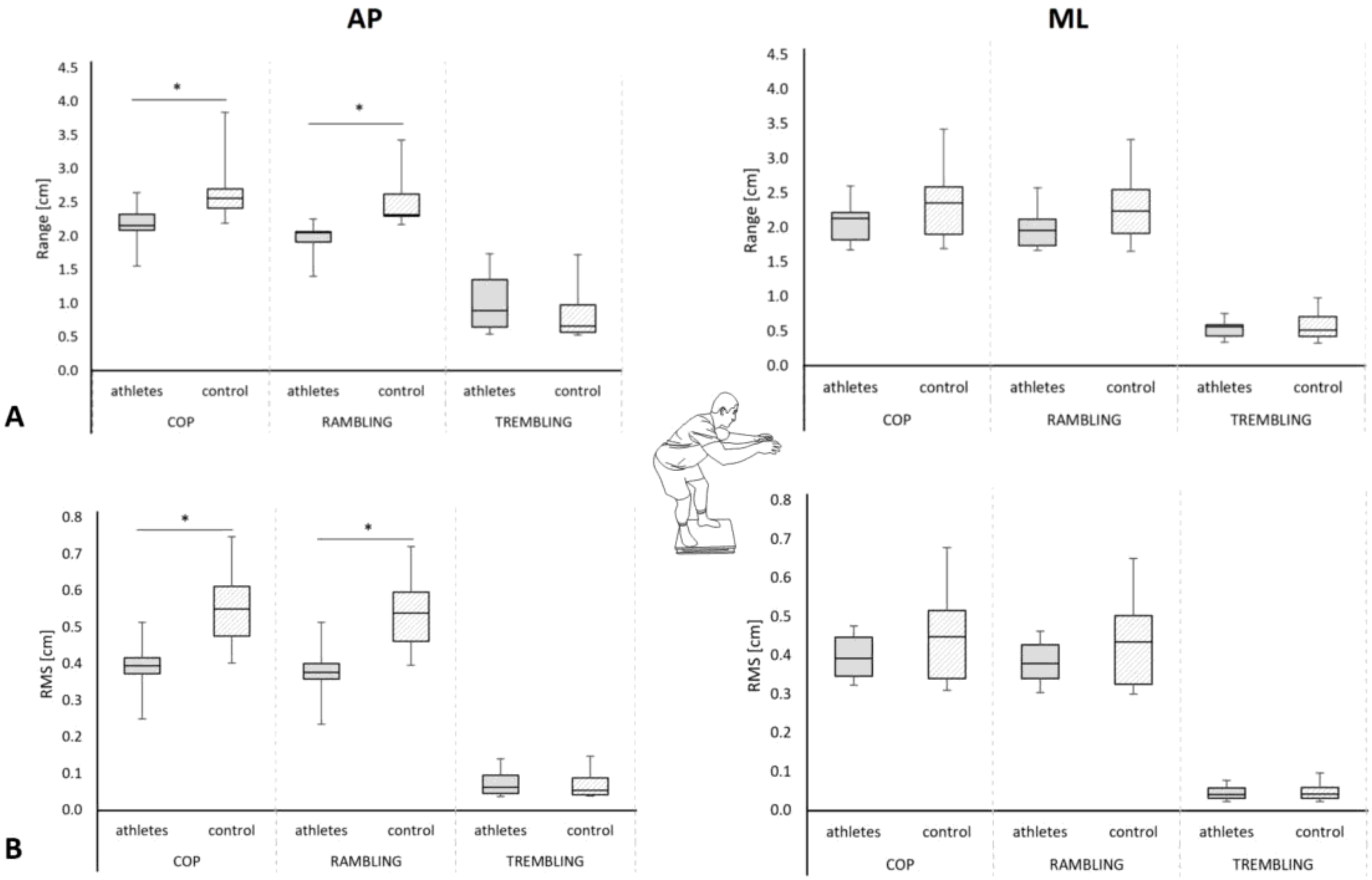

Figure 4

Comparison between groups in combat stance. Legend: (A) range of COP, rambling, and trembling, and (B) root mean square (RMS), rambling, and trembling in the anterior-posterior (AP) and mediolateral (ML) directions (median, upper, and lower quartile, min. and max. marked as error bars) (*p < 0.05).

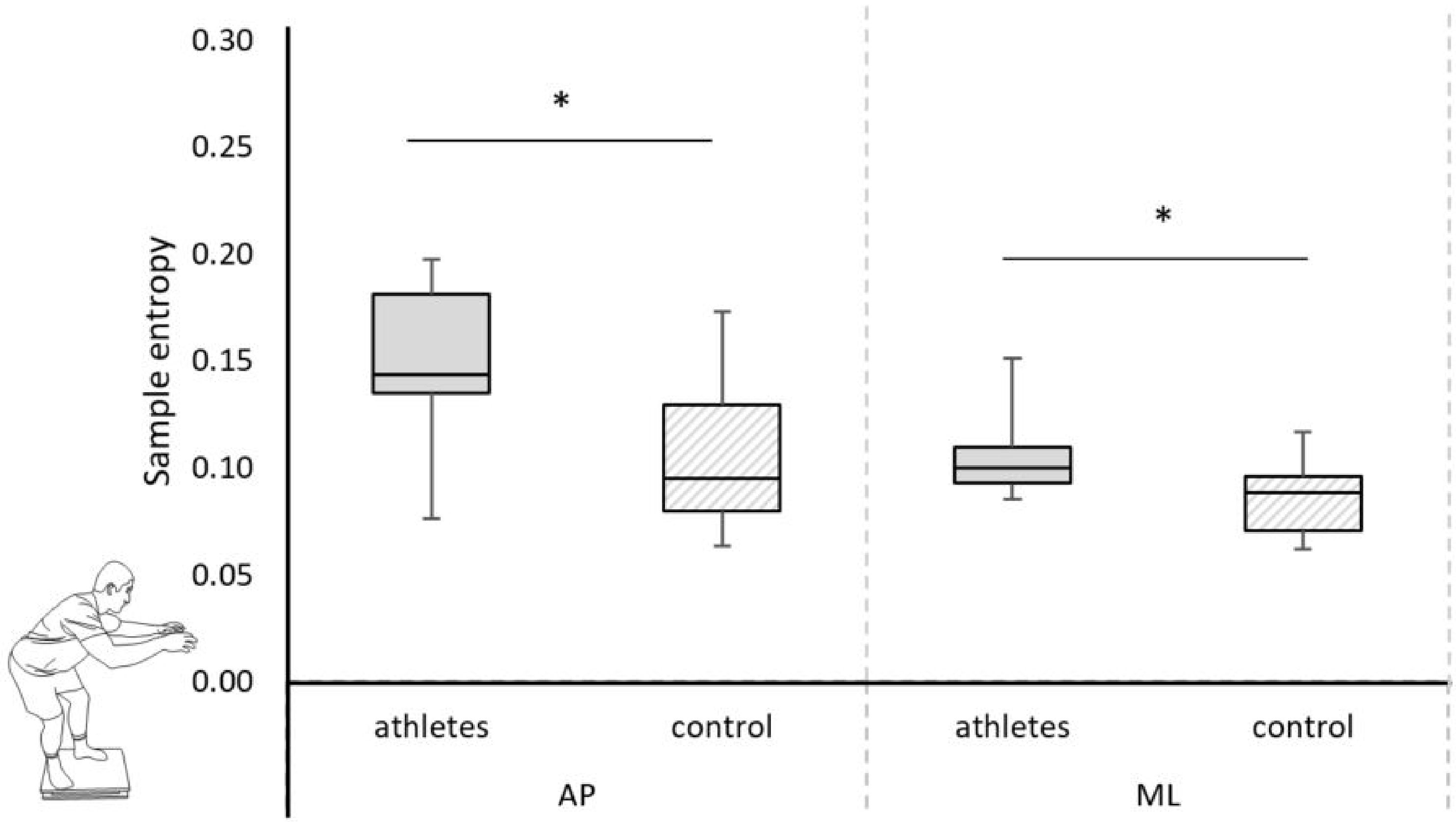

Figure 5

Comparison between groups of the sample entropy in combat stance. Legend: anterior-posterior (AP) and mediolateral (ML) directions (median, upper, and lower quartile, min. and max. marked as error bars) (*$p < 0.05$).