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Title:

Dynamics of postural control in elite sport rifle shooters

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Abstract

The present study investigated the dynamics and spatial magnitude of the center of pressure trajectories during stance tasks in elite sport rifle shooters and non-shooters. Thirteen shooters and eleven non-shooters completed 90 seconds of two-legged and single legged stance on a force platform. The dynamics of the center of pressure trajectory was assessed using sample entropy, correlation dimension and entropic half-life. Additionally, the body sway was quantified as the elliptical area of the trajectory. The shooters had lower sample entropy and tended to have longer entropic half-life in both directions during the single-legged stance. Across the two tasks, lower correlation dimension in the anterior-posterior direction and lower body sway in both directions was observed in the shooters when compared to the non-shooters. This suggests that extensive training in maintaining quiet upright stance is associated with altered postural control, especially during challenging single-legged stance and to a lesser extend during a simpler two-legged standing task. Thus, the sport rifle shooters solved the difficult single-legged standing task using a movement pattern with increased regularity and lower dimensionality and body sway when compared to non-shooters.

Keywords: nonlinear dynamics; stance; sport shooting; variability

Introduction

Maintaining balance during quiet upright single-legged or two-legged stance is a seemingly simple task which easily can be performed by young healthy individuals. However, impaired neuromuscular function following pathology (Pelykh, Klein, Botzel, Kosutzka, & Ilmberger, 2015; Roerdink et al., 2006), injuries (Hertel & Olmsted-Kramer, 2007; Hertel, Olmsted-Kramer, & Challis, 2006; Riemann, 2002) or aging (Baltich, von Tscharner, & Nigg, 2015) has been shown to affect the movement pattern during upright standing. Equally, infancy and childhood maturation seem to influence the postural motor control (Harbourne & Stergiou, 2003). Studies of upright stance have shown that the center of pressure trajectory contains a time dependent dynamics meaning that movements have a temporal correlation and that this dynamics reflects the executed postural motor control (Collins & De Luca, 1993, 1995; Newell, van Emmerik, Lee, & Sprague, 1993). While most traditional linear analytical tools applied to center of pressure trajectories quantify spatial aspects and therefore ignore this particular dynamics, important motor control information may be overlooked by only using such methods (Harbourne & Stergiou, 2003; Newell et al., 1993). Instead, analyzing the dynamics of the center of pressure trajectory during these postural control tasks using various nonlinear mathematical methods acknowledges the time dependency of the executed movements and can provide detailed information of the underlying motor control strategy (Harbourne & Stergiou, 2003, 2009; Stergiou & Decker, 2011). When investigating the development of sitting postural control in infants, Harbourne and Stergiou (2003) quantified entropy and correlation dimension to assess regularity and dimensionality of the center of pressure trajectory. The authors were able to distinguish the executed motor control strategy of the infants at three different developmental stages using the nonlinear methods, whereas linear methods did not reveal any changes. Regularity and dimensionality of center of pressure trajectories can be interpreted as two measures of the organization of the movement solution space (Kay, 1988; Newell, 1997). Higher values indicate an unpredictable (high entropy) and less structured (high dimensionality) solution space with more potential movement solutions and lower values indicate a more predictable (low entropy) and structured (low dimensionality) solution space with fewer potential solutions (Raffalt, Spedden, & Geertsen, 2019). One drawback of the mentioned nonlinear methods is that they do not return an output in a physiological or biomechanical interpretable scale. Recently, entropic half-life was introduced as a measure of time dependency in an interpretable time scale (i.e. seconds) (Federolf, Zandiyeh, & Von Tscharner, 2015; Zandiyeh & Von Tscharner, 2013). Entropic half-life quantifies the elapsed time before positional information from previous movements no longer affects the control of current movements. Thus, low values indicate little time dependency and vice versa. Using entropic half-life, Baltich et al. (2015) observed a shorter time dependency of the center of pressure trajectory in the anterior-posterior direction for older adults compared to younger adults. This was interpreted as the older individuals had more frequent postural adjustments compared to the younger individuals.

While few people practice quiet stance in their everyday-life, elite athletes within certain sports such as sport shooting spend numerus training hours each day with the purpose of maintaining upright stance as quiet as possible. Thus, these individuals are experts in postural standing when compared to healthy non-athletes (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Mononen, Konttinen, Viitasalo, & Era, 2007). Using linear methods to evaluate the center of pressure trajectory, previous studies have revealed that expert rifle shooters exhibited more stable posture compared to novice shooters (Era et al., 1996) and non-shooters (Aalto, Pyykko, Ilmarinen, Kahkonen, & Starck, 1990) during a shooting-like bilateral stance task. Additionally, in two recent studies, Ko and colleagues (Ko, Han, & Newell, 2017, 2018) observed that skilled sport pistol shooters had lower variability and complexity in their center of pressure movements when compared to novice individuals. However, beside complexity these studies did not assess other characteristics of the center of pressure dynamics. It has previously been suggested that a reduction of complexity in human movements can be characterized by both decreased and increased movement regularity (Stergiou, Harbourne, & Cavanaugh, 2006). Following this idea, it seems more plausible that the reduced complexity of the stable stance performed by sport pistol shooters is achieved by increasing the regularity of the center of pressure pattern and not by reducing it (i.e. moving in a more periodic-like manner). This suggests that entropy and dimensionality would be lower and that the time dependency would be higher in shooters compared to non-shooters. Furthermore, the aforementioned studies by Era et al. (1996), Aalto et al. (1990) and Ko et al. (2017, 2018) suggest that extensive practice of stable upright stance significantly alter the postural control during a training specific task. However, it is unknown if the altered postural control is specific to the nature of the trained task (two-legged stance) or it can be incorporated to another more difficult balance task (single-legged stance).

The purpose of the present study was to investigate the dynamics of the center of pressure trajectories during a relatively easy postural balance task (two-legged stance) and a relatively difficult balance task (single-legged stance) in elite sport rifle shooters and non-shooters. The dynamics of the center of pressure trajectories was assessed by sample entropy (Richman & Moorman, 2000), correlation dimension (Grassberger & Procaccia, 1983) and entropic half-life (Baltich, Von Tscharner, Zandiyeh, & Nigg, 2014; Zandiyeh & Von Tscharner, 2013). Anecdotally, sport rifle shooters strive to stand 'as quiet as possible' during competitions and training based on the intuitive logic of this being advantageous for precision shooting. To verify that shooters are capable of standing ‘more quiet’ compared to non-shooters, the spatial body sway was quantified as the elliptical area of the combined center of pressure trajectory. We hypothesized that the dynamics of postural control during the two balance tasks in elite sport rifle shooters would be characterized by higher regularity (lower sample entropy), lower dimensionality (lower correlation dimension), longer time dependency (higher entropic half-life), and lower body sway (smaller elliptical area) when compared to non-shooters.

Materials and methods

Participants

Thirteen elite sport rifle shooters (7 females/6 males, mean ± SD age: 20.2 ± 4.0 years, body mass: 71.0 ± 14.0 kg and body height: 1.74 ± 0.11 m) of high international and national level and eleven non-shooters (7 females/4 males, mean ± SD age: 28.1 ± 4.9 years, body mass: 71.1 ± 10.5 kg and body height: 1.75 ± 0.09 m) were recruited to the present study. The participants were not matched and the non-shooters were older than the shooters but no statistically significant group-differences were observed in body mass and height. Prior to the experimental sessions, all participants gave their informed written consent to participate. The experiment was conducted in accordance with the Helsinki declaration.

Experimental setup

The participants performed 90 seconds of 1) barefooted shoulder wide two-legged stance and 2) single-legged stance on the right foot stance on a force plate (AMTI OR6-7). The participants were instructed to keep hands akimbo during both trials, to avoid resting the left foot on the right leg during the single-legged stance trial and to fix their gaze on a target (black spot on a white piece of paper) placed on the wall approximately 3 meters in front of them. The right foot was chosen for analysis since all sport rifle shooters had the same side (the left) closest to the target and the right foot furthest away from the target. The sessions were separated by at least one minute of rest. The three dimensional ground reaction forces and moments were recorded at 1000 Hz and the anterior-posterior and mediolateral center of pressure trajectories were extracted for the middle 60 seconds of each trial.

Analysis

The center of pressure time series (Figure 1) were filtered using a Daubechies wavelet and down sampled to 100 Hz before exposed to the nonlinear analyses (Baltich et al., 2015; Baltich et al., 2014; Federolf et al., 2015). All analyses were conducted in custom written Matlab scripts (MathWorks R2011b).

The regularity of the time series was evaluated by sample entropy using the equation presented by Richman and Moorman (Richman & Moorman, 2000) with a vector length *m* of 2 and a tolerance limit *r* of 0.2. To control for input parameter consistency, sample entropy was calculated using combinations of m = 2 and 3 and r = 0.1, 0.15, 0.2, 0.25 and 0.3. The results of these calculations are summarized in the Results paragraph and presented in the supplementary material. Each time series was reconstructed in state space using the method of delayed embedding before calculating correlation dimension (Sauer, Yorke, & Casdagli, 1991; Takens, 1981). Time delay and embedding dimension were calculated using the Average Mutual Information and False Nearest Neighbor algorithms, respectively (Wurdeman, 2016). The mean time delay and embedding dimension across all participants, trials and directions were calculated and rounded to nearest integers (time delay = 29 and embedding dimension = 5). The time delay and embedding dimension of each participant, trial, and direction are presented in the supplementary material. Correlation dimension was calculated using the equations presented by Grassberger and Procaccia (Grassberger & Procaccia, 1983). Entropic half-life was calculated using the procedure previously described by Zandiyeh and von Tscharner (2013) and Baltich et al. (2014). The procedure included 4 steps: Step 1) The original time series was gradually randomized through a reshaping procedure according to the following principle. The first reshaped time series was equal to the original time series (e.g. [1 2 3 4 5 6 7 8 9 10 11 12]). The second reshaped time series would have a reorganization of every second data point (e.g. [1 3 5 7 9 11 2 4 6 8 10 12]), the third reshaped time series would have a reorganization of every third data point (e.g. [1 4 7 10 2 5 8 11 3 6 9 12]) and so on. When the time series was down sampled to 100 Hz, there was 10 ms between each data point. For the second reshaped time series, there was 20 ms between two adjacent data points, for the third reshaped time series, there was 30 ms between two adjacent data points and so on. This reshaping procedure was iterated 100 times. Step 2) Sample entropy was calculated for each reshaped time series with m=2 and r=0.2. Step 3) The sample entropy from each reshaped time series were normalized by first subtracting the sample entropy of the original time series and then dividing it by the difference between the average sample entropy of 50 completely randomized time series and the sample entropy of the original time series. The randomized time series were created by a random permutation of the data points in the original time series. Step 4) The normalized sample entropy values from the reshaped time series were plotted in a semi logarithmic plot as a function of the reshaping time. Entropic half-life was identified as the time at which the normalized sample entropy increased above 0.5 (Zandiyeh & Von Tscharner, 2013). Additionally, body sway was quantified by the elliptical area calculated as the standard deviation of the center of pressure trajectories in both directions multiplied by pi.

Statistics

Residual normality and data homogeneity were confirmed using Shapiro-Wilk test and Levene's test of equality before conducting the following statistical analysis. To investigate the effect of group and task on the sample entopy, correlation dimension and entropic half-life, a two way mixed-design ANOVA with group (between-participants) and task (within-participants) as independent factors was applied to the dependent variables in each center of pressure direction. In case of an overall effect of group or task or the interaction (group x task), a Holm-Sidak post hoc test was applied to locate the differences. Mean differences, 95% confidence interval of differences (95%CI) and effect sizes were calculated for significant post hoc group or task differences. Effect sizes were evaluated as trivial (0 – 0.19), small (0.20 – 0.49), medium (0.50 – 0.79) and large (above 0.8) using Cohen’s d (Cohen, 1992). An effect size above 0.2 was considered to be practically relevant. Level of significance was set at 5%. All statistical calculations were performed in Sigmaplot (Systat Software, Inc. 2014, version 13.0, Germany).

Results

Regularity

Sample entropy showed a similar tendency for the two center of pressure directions. There was a significant effect of group (anterior-posterior: $F = 18.0$, $df = 1$, $p < 0.0001$; mediolateral: $F = 27.6$, $df = 1$, $p < 0.0001$), task (anterior-posterior: $F = 40.0$, $df = 1$, $p < 0.0001$; mediolateral: $F = 22.6$, $df = 1$, $p < 0.0001$) and a significant group-task interaction (anterior-posterior: $F = 14.5$, $df = 1$, $p = 0.001$; mediolateral: $F = 29.5$, $df = 1$, $p < 0.0001$) (Figure 2A and 2B). The post-hoc tests revealed that the sport rifle shooters had significantly lower sample entropy during the single-legged stance (anterior-posterior: mean difference: 0.070, 95%CI: 0.036 – 0.104, $p < 0.0001$, $d = 1.76$; mediolateral: mean difference: 0.113, 95%CI: 0.081 – 0.144, $p < 0.0001$, $d = 3.05$) but not during the two-legged stance compared to the non-shooters. Furthermore, the sample entropy during the single-legged stance was significantly higher when compared to the two-legged stance for the non-shooters (anterior-posterior: mean difference: 0.078, 95%CI: 0.055 – 0.101, $p < 0.0001$, $d = 1.98$; mediolateral: mean difference: 0.102, 95%CI: 0.073 – 0.132, $p < 0.0001$, $d = 2.26$) but not for the sport rifle shooters (Figure 2A and 2B). The parameter consistency test (see supplementary material) showed that the between-group and between-task relationships were consistent across all investigated input parameter combinations. This validates the used input parameters ($m=2$ and $r=0.2$) for the sample entropy calculations.

Dimensionality

There was a significant effect of group on correlation dimension in the anterior-posterior direction ($F = 8.8$, $df = 1$, $p = 0.007$) and of task in both directions (anterior-posterior: $F = 5.2$, $df = 1$, $p = 0.033$; mediolateral: $F = 12.8$, $df = 1$, $p = 0.002$) (Figure 4A and 4B). In the anterior-posterior direction, the sport rifle shooters had lower correlation dimension compared to the non-shooters and when comparing tasks, the correlation dimension in both directions was higher during the single-legged stance compared to the two-legged stance.

Level of time dependency

There was a significant effect of task on the entropic half-life in both directions (anterior-posterior: $F = 20.4$, $df = 1$, $p < 0.0001$; mediolateral: $F = 7.9$, $df = 1$, $p = 0.011$) with the entropic half-life being shorter during the single-legged task compared to the two-legged task (Figure 5A and 5B). Although no significant interaction was observed for entropic half-life in the two directions, it is noteworthy that the entropic half-life appeared to be substantially shorter during the single-legged stance for the non-shooters when compared to the sport rifle shooters.

Body sway

There was a significant effect of group ($F = 10.4$, $df = 1$, $p = 0.04$), task ($F = 105.3$, $df = 1$, $p < 0.0001$) and a significant group-task interaction ($F = 5.5$, $df = 1$, $p = 0.028$) on the body sway (Figure 6). The post-hoc test revealed that the sport rifle shooters had significantly lower body sway during both tasks than the non-shooters (two-legged: mean difference: 11.52, 95%CI: 6.58 – 16.47, $p < 0.0001$, $d = 1.98$; single-legged: mean difference: 74.35, 95%CI: 19.15 – 129.55, $p < 0.0001$, $d = 1.14$). Furthermore, both groups had significantly greater body sway during the single-legged stance compared the two-legged stance (shooters: mean difference: 108.19, 95%CI: 70.58 – 145.80, $p < 0.0001$, $d = 2.15$; non-shooters: mean difference: 171.02, 95%CI: 130.13 – 211.90, $p < 0.0001$, $d = 4.90$) (Figure 6).

Discussion

The present study investigated the dynamics and spatial magnitude of the center of pressure trajectories during bilateral and unilateral stance in sport rifle shooters and non-shooters. It was hypothesized that the sport rifle shooters would exhibit higher regularity, lower dimensionality, longer time dependency, and lower body sway than the non-shooters. This hypothesis was not confirmed for the two-legged stance but fully confirmed for the single-legged stance. This indicates that the postural control strategy only differs between the sport rifle shooters and non-shooters during a more challenging balance task. Each of the investigated parameters quantifies a specific characteristic of the investigated time series and can be interpreted as an outcome of the executed motor control strategy.

Regularity of stance

Sample entropy was used to quantify regularity of the center of pressure trajectory. This measure has previously been used to indicate changes in the utilized functional degrees of freedom within the human movement system in response to external restrictions, altered internal neuromuscular noise and sensory information or altered movement strategy (Kay, 1988; Newell, 1997). While two-legged stance did not resulted in any group difference in sample entropy, it was observed that the sport rifle shooters had significantly higher regularity (i.e. lower sample entropy) during the single-legged stance when compared to the non-shooters. This suggests that the motor control strategy of the athletes resulted in a more predictable movement solution space with fewer functional degrees of freedom than that of the non-shooters. In agreement with the theory of ‘optimal movement variability’ (Stergiou et al., 2006), the results of the present study indicate the complexity in the executed movement is reduced by an increase in regularity. Altogether, these observations seem to agree with the previous studies by Ko and colleagues, who used multiscale entropy and detrended fluctuation analysis and observed a lower complexity in the postural control of elite pistol shooters compared to novices (Ko et al., 2017, 2018). It is imperative to avoid addressing increase or decrease in sample entropy as universally ‘positive’ or ‘negative’. According to Stergiou et al. (2006), movement complexity can be reduced by both a decrease and increase in movement regularity. Thus, when sport shooters exhibit lower complexity (Ko et al., 2017, 2018), they are likely doing so by ‘actively’ increasing the movement regularity to enhance their ‘quiet’ stance. In contrast, when older adults have an involuntary loss of complexity it can be accompanied by both a decrease (Borg & Laxaback, 2010; Raffalt, Spedden, et al., 2019) and an increase in center of pressure regularity (Raffalt, Spedden, et al., 2019). These bi-directional changes in regularity with aging have been proposed to be task dependent (Vaillancourt & Newell, 2003).

Dimensionality of stance

Interestingly, an overall group effect was observed for correlation dimension in the anterior-posterior direction but not in the mediolateral direction. This directional-dependent group effect was only present for this variable and revealed that the sport shooters had lower dimensionality compared to the non-shooters. Considering the execution of the sport performance during training and competition, where the target is placed laterally to the athlete, it could be speculated that the executed motor control in the anterior-posterior direction is more determinant for a steady aim than in the mediolateral direction. This seems to be confirmed by the dimensionality results, suggesting that the movement solution space in the anterior-posterior direction is more structured and restricted in the sport shooters compared to the non-shooters. Assuming a causal link between the extensive training in postural control conducted by elite athletes within sport pistol and rifle shooting and the altered postural control, the aforementioned and present study suggest that deliberate practice can reduce the complexity of the executed movements. This seems to be supported by Ko and Newell (2015), who observed a reduction dynamical degrees of freedom in postural control during standing balance following three days of balance practice.

Time dependency of stance

Entropic half-life quantifies the time dependency of continuous signals and estimates the elapsed time before positional information from previous completed movements no longer influences the control of the current movements. This parameter can be influenced by the number of mechanically equivalent movement configurations (i.e. the number of movement configurations that lead to the same stable behavior) and the applied motor control (Federolf et al., 2015). Although no statistical significant task-group effect was observed due to similar entropic half-life values during two-legged stance, the entropic half-life was more than 100ms longer in both directions for the sport rifle shooters during the single-legged stance indicating that the executed motor control relied on positional information obtained further back in time and less frequent postural adjustments were made when compared to the non-shooters. In agreement with a previous study by Federolf and colleagues on healthy young individuals (Federolf et al., 2015), the entropic half-life in the anterior-posterior direction appeared to be longer compared to the mediolateral direction during both two-legged and single-legged stance. This agrees with the notion that more mechanical equivalent movement configurations are available to keep stable balance in the mediolateral direction than in the anterior-posterior direction (Federolf et al., 2015).

Body sway and performance

The body sway was calculated to quantify the ‘level of quiet stance’ performance for the two groups during the two stance tasks. Based on anecdotes, sports rifle shooters attempt to minimize their body sway to stand ‘as quiet as possible’ and it was hypothesized that this group would outperform the non-shooters on this parameter. This hypothesis was confirmed. The results of the present study confirm a large body of literature indicating that ‘quiet stance’ does not mean a minimization of body sway but does indeed contain a portion of center of pressure motion (Thomas A. Stoffregen, Pagulayan, Bardy, & Hettinger, 2000; Thomas A. Stoffregen, Smart, Bardy, & Pagulayan, 1999; T. A. Stoffregen, Villard, & Yu, 2009). Anecdotally, sport rifle and pistol shooters are known to attempt to stand as quiet as possible during training and competition because increased quiet stance is believed to increase aiming accuracy (Era et al., 1996; Mononen et al., 2007). The present results indicate that the applied motor control strategy lead to a more ‘quiet’ movement pattern during upright stance in the sport rifle shooters. It is noteworthy that while the linear measure of body sway differed between groups during the two-legged stance, the only non-linear measure that differed significantly between the two groups was the correlation dimension in the anterior-posterior direction. This indicates that while the two groups share similar motor control dynamics, the sport shooters performed significantly more ‘quiet’ two-legged stance compared to the non-shooters. It could be speculated that the extensive training background of the athletes has led to adaptations in passive structures (e.g. tendons and intramuscular connective tissue), which alter the muscle-tendon and tendon-bone force transmission compared to that of non-shooters. It could be speculated that this changes the body sway of the sport shooters, although, the motor control strategy is not different from the non-shooters.

While the sport shooters did not have different movement dynamics during the simpler task of two-legged stance, group differences appeared during the more difficult single-legged stance. This seems somewhat paradoxical, considering that single-legged stance does not appear to be crucial for sport shooting, as this is a task performed with two-legged stance. Interestingly, relatively few significant differences in center of pressure dynamics were observed between two-legged and single-legged stance for the sport rifle shooters, suggesting that their motor control strategy and executed movement pattern were comparable during these two tasks. In contrast, substantial task differences were observed for almost every investigated variable for the non-shooters. This indicates that the extensive postural control training conducted by the athletes significantly reduces the body sway compared to non-shooters during both tasks but primary alters the motor control of the relative difficult single-legged stance task. Thus, it could be speculated that the sport rifle shooters are able to solve both tasks using the same motor control strategy to improve their ‘quiet stance’ performance.

Study limitations and perspectives

The present study did not control for leg or hand dominance in the participants for the single-legged stance task. The right side was chosen because all shooters performed shooting during everyday training and competitions with the same side (left) closest to the target. The non-shooters also performed single-legged stance on their right leg regardless of their potential leg dominance side. It cannot be excluded that this methodological choice could bias the results. However, previous studies on healthy young individuals have shown a high level of leg symmetry during two-legged stance (Wang, Jordan, & Newell, 2012; Wang & Newell, 2012). The present study included three nonlinear methods (sample entropy, correlation dimension and entropic half-life) to quantify the dynamics of the center of pressure trajectories. Similar approach has recently been used in two studies to successfully differentiate the center of pressure dynamics between younger and older individuals (Raffalt, Spedden, et al., 2019) and between ankle instable individuals and healthy individuals (Raffalt, Chrysanthou, Duda, & Agres, 2019).

Many nonlinear tools including correlation dimension are sensitive to noise in the investigated time series. In acknowledgement of this, the present study applied similar filtering approach as Federolf et al. (2015), Baltich et al. (2014) and Baltich et al. (Baltich et al., 2015).

The design of the present study does not allow causal inference regarding shooting training and postural control. Thus, while the notion that the extensive training of elite shooters alters the dynamics of postural control seems plausible, a genetic predisposition in those individuals who become successful sport shooters cannot be excluded. Interestingly, Baltich and colleagues recently investigated the dynamics postural control in elderly and young individuals by quantifying entropic half-life during single legged stance (Baltich et al., 2015). They observed that elderly individuals had shorter entropic half-life (approximately 80 ms) compared to young individuals (160 ms) in the anterior-posterior direction and larger center of pressure trajectory area. This observation seems to agree well with the results of the present study. While the degradation of the neuromuscular control with aging change the movement strategy towards less time dependency leading to larger center of pressure sway area, optimization of the motor control results in more time dependency and smaller center of pressure sway area during single-legged stance. Whether balance training in elderly would lead to an alteration of the movement strategy towards that of healthy young individuals and sport rifle shooters remains to be investigated.

Based on the present results, a single-legged stance task is sensitive enough to distinguish the movement dynamics in terms of regularity and body sway between the sport rifle shooters and non-shooters. It could be speculated that such a balance task with the quantification of sample entropy and body sway is also able to distinguish the dynamics between athletes of various levels. From an athlete’s perspective, it could be suggested that specific postural training should aim at developing a regular, periodical and small body sway as this seems to characterize expert rifle shooters.

Conclusion

The results of the present study suggest that extensive training in maintaining quiet upright stance is associated with the ability to solve a more challenging non-specific single-legged stance task with a similar motor control strategy as during a more sport specific but simpler two-legged stance task. Furthermore, sport rifle shooters solved the single-legged standing task using a movement pattern of increased regularity and lower dimensionality and body sway compared to non-shooters.

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Conflict of interest

The authors declare no conflict of interest.

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Legends

Figure 1: Centre of pressure trajectory for the two-legged and single-legged stance for a representative individual form each group.

Figure 2: Mean ± SEM sample entropy for the sport-rifle shooters and non-shooters during the two-legged (TL) and single-legged (SL) stance in the anterior-posterior (A) and mediolateral (B) direction. Overall significant effect of group, task and group-task interaction is indicated by the p-values in the top of the figure. Post hoc differences are indicated by horizontal lines with corresponding p-values.

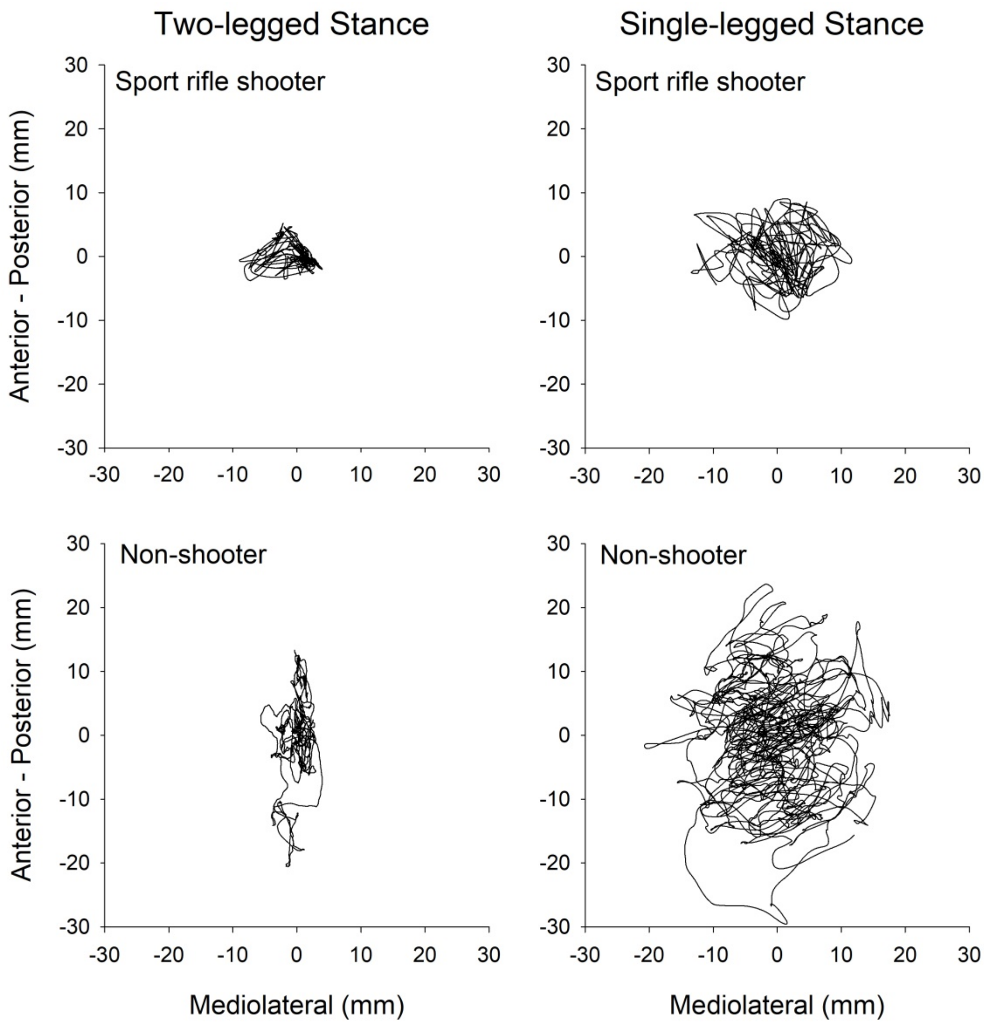
Figure 3: Mean ± SEM correlation dimension for the sport-rifle shooters and non-shooters during the two-legged (TL) and single-legged (SL) stance in the anterior-posterior (A) and mediolateral (B) direction. Overall significant effect of group and task is indicated by the p-values in the top of the figure. NS: no significant effect.

Figure 4: Mean ± SEM entropic half-life for the sport-rifle shooters and non-shooters during the two-legged (TL) and single-legged (SL) stance in the anterior-posterior (A) and mediolateral (B) direction. Overall significant effect of group and task is indicated by the p-values in the top of the figure. NS: no significant effect.

Figure 5: Mean ± SEM body sway for the sport-rifle shooters and non-shooters during the two-legged (TL) and single-legged (SL) stance. Overall significant effect of group, task and group-task

interaction is indicated by the p-values in the top of the figure. Post hoc differences are indicated by horizontal lines with corresponding p-values.

Figure 1:



Two-legged Stance
Single-legged Stance
Sport rifle shooter
Sport rifle shooter
Non-shooter
Non-shooter
Anterior - Posterior (mm)
Anterior - Posterior (mm)
Mediolateral (mm)
Mediolateral (mm)
30
20
10
0
-10
-20
-30
-30
-20
-10
0
10
20
30

Figure 2:

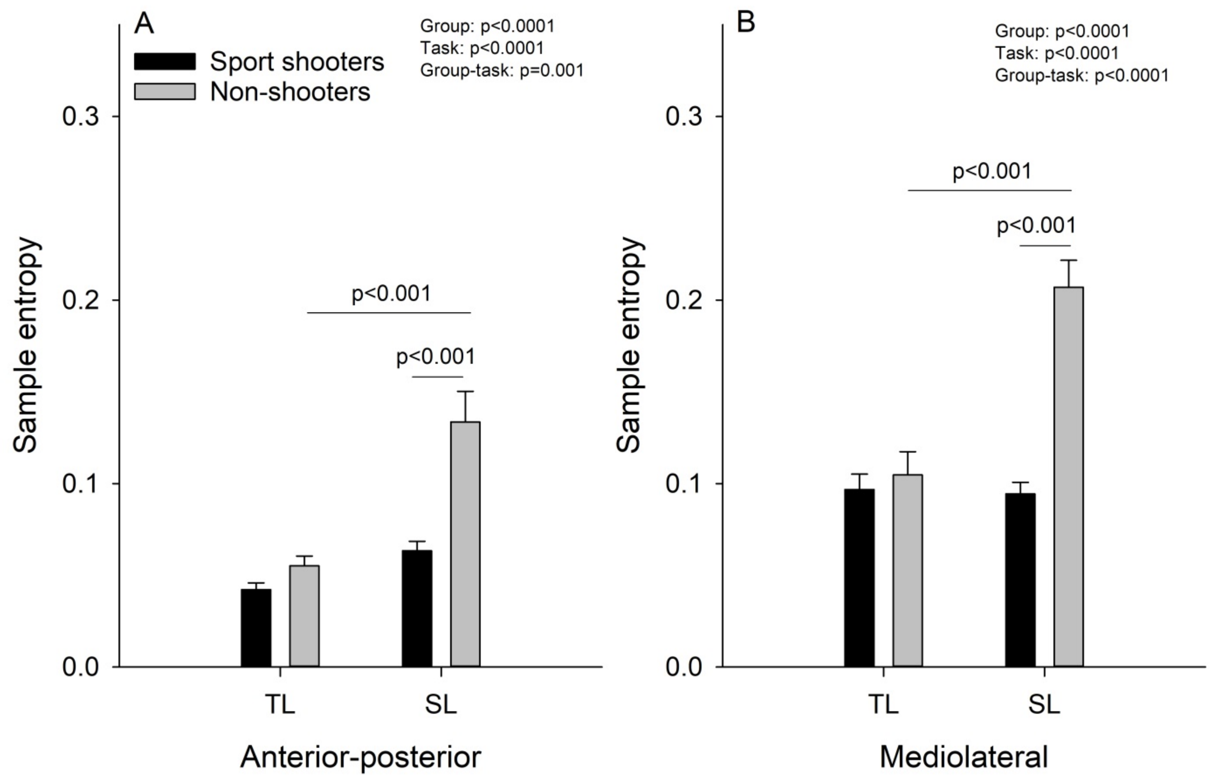
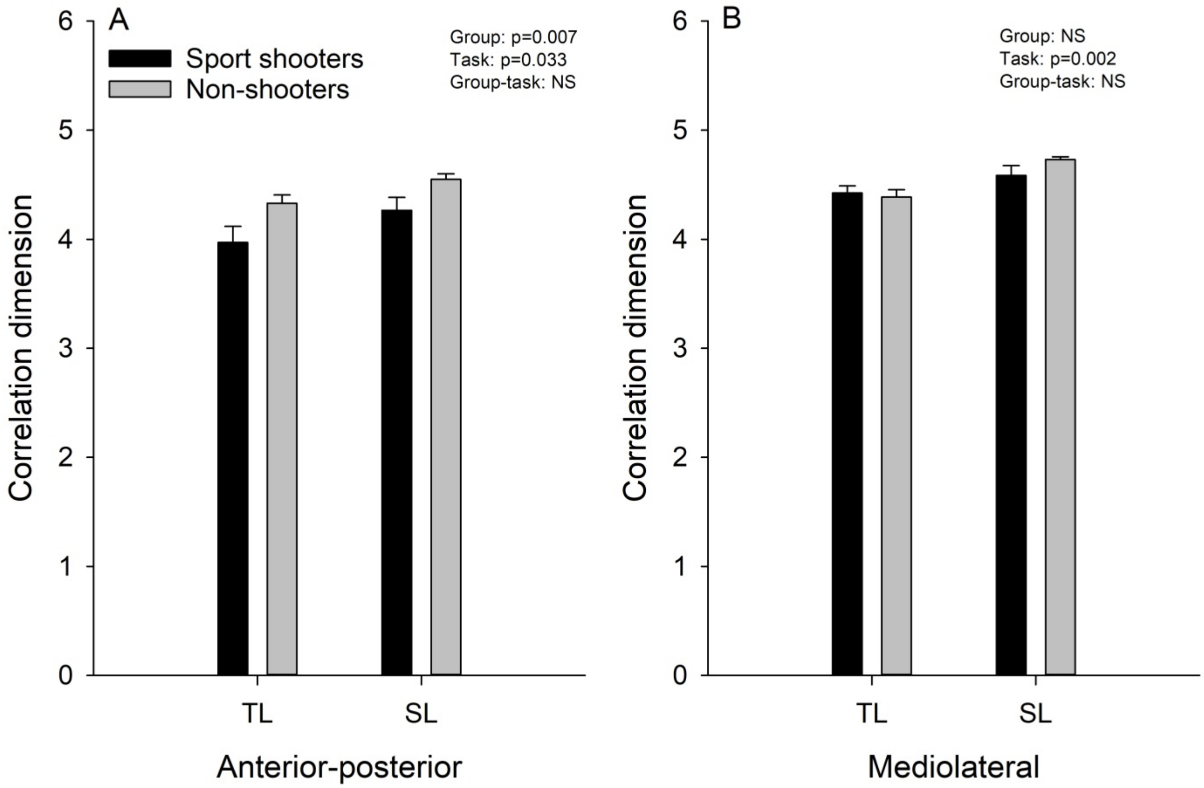

A
Sport shooters
Non-shooters
Group: p<0.0001
Task: p<0.0001
Group-task: p=0.001
Sample entropy
0.3
0.2
0.1
0.0
p<0.001
p<0.001
TL
SL
Anterior-posterior
B
Group: p<0.0001
Task: p<0.0001
Group-task: p<0.0001
Sample entropy
0.3
0.2
0.1
0.0
p<0.001
p<0.001
TL
SL
Mediolateral

Figure 3:



A
Sport shooters
Non-shooters
Group: p=0.007
Task: p=0.033
Group-task: NS
Correlation dimension
0
1
2
3
4
5
6
TL
SL
Anterior-posterior
B
Group: NS
Task: p=0.002
Group-task: NS
Correlation dimension
0
1
2
3
4
5
6
TL
SL
Mediolateral

Figure 4:

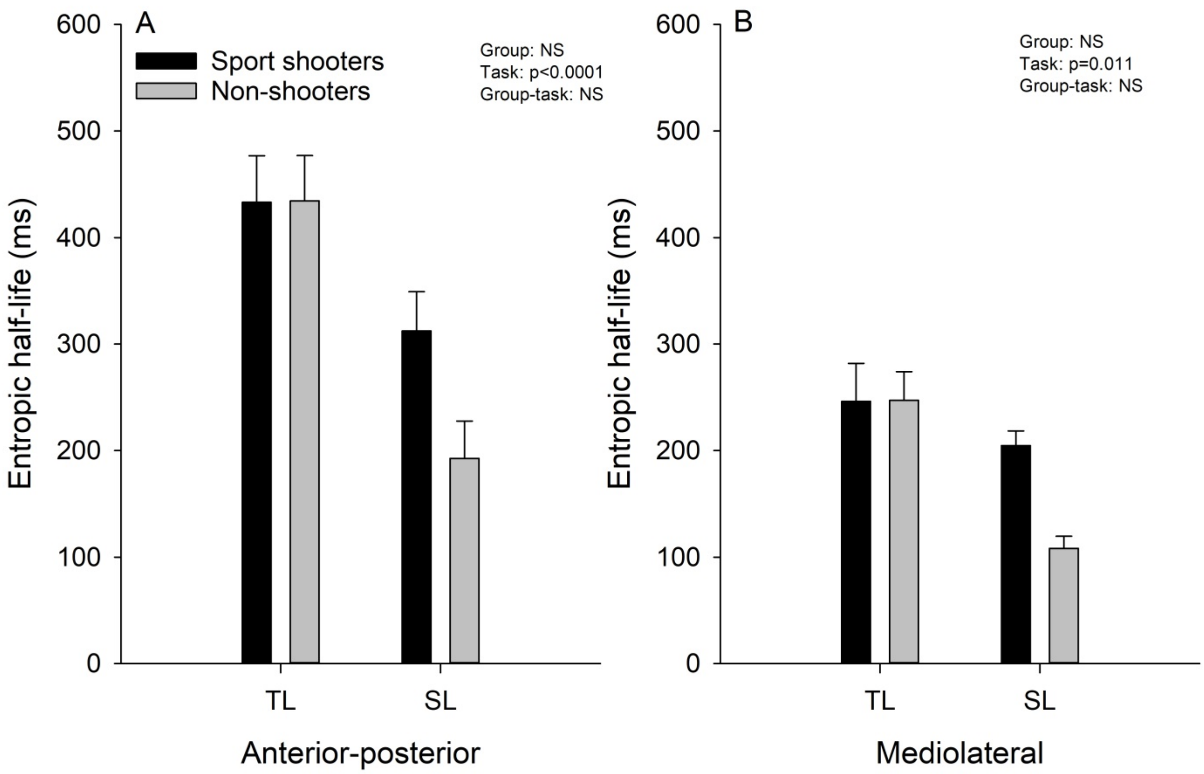
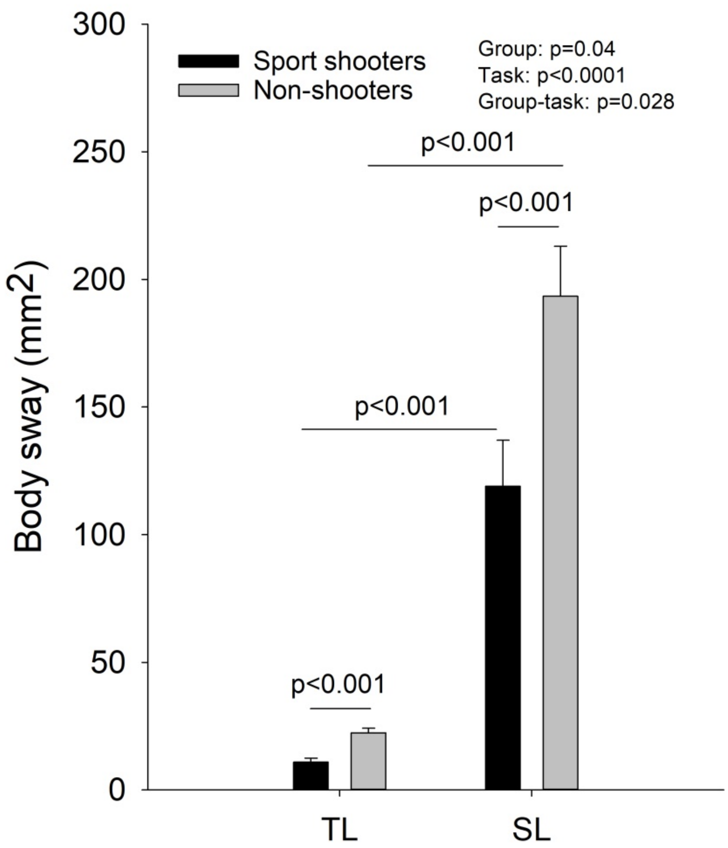

A
Sport shooters
Non-shooters
Group: NS
Task: p<0.0001
Group-task: NS
Entropic half-life (ms)
600
500
400
300
200
100
0
TL
SL
Anterior-posterior
B
Group: NS
Task: p=0.011
Group-task: NS
Entropic half-life (ms)
600
500
400
300
200
100
0
TL
SL
Mediolateral

Figure 5:



Sport shooters
Non-shooters
Group: p=0.04
Task: p<0.0001
Group-task: p=0.028
p<0.001
p<0.001
p<0.001
p<0.001
Body sway (mm2)
300
250
200
150
100
50
0
TL
SL