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Originales

Comparison of centre-of-pressure movement variability between elite and non-elite wrestlers during a wrestling stance task



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ABSTRACT

This study compared the variability of centre of pressure (CoP) movement between elite and non-elite wrestlers during a repetitive wrestling stance task. Sixty male wrestlers (30 elite, 30 non-elite) performed a simulated 30 s protocol involving short-cycle repetitive wrestling stance tasks under two conditions: dominant and non-dominant leg. Non-linear Poincaré analysis was applied to the medial-lateral (ML) and anterior-posterior (AP) directions and to total (T) CoP displacement, computing short-term (SD1) and long-term (SD2) variability indicators. A mixed-model ANOVA with Bonferroni correction was used. Non-elite wrestlers showed significantly higher SD1 ($p = .018$) and SD2 ($p = .008$) in the ML direction of the dominant leg, whereas no differences appeared in the AP direction or in T displacement. Between legs, elite wrestlers differed significantly in SD1 ($p = .008$) and SD2 ($p = .014$) in the AP direction and in SD1 ($p = .025$) and SD2 ($p = .039$) of T displacement. No differences were found between the beginning and the end of the task. Poincaré analysis is a useful procedure for monitoring CoP movement variability during back-and-forth movements in wrestling.

Keywords: Dynamic postural control; Poincaré plot analysis; Back-and-forth movements; Performance evaluation; Wrestling.

Comparación de la variabilidad del desplazamiento del centro de presiones entre luchadores de élite y no élite durante una tarea de posición de guardia

RESUMEN

El objetivo de este estudio fue comparar la variabilidad del desplazamiento del centro de presiones (CdP) entre luchadores de élite y no élite durante una tarea repetitiva de posición de guardia. Sesenta luchadores varones (30 de élite y 30 no élite) realizaron un protocolo simulado de 30 s de ciclos cortos repetitivos en posición de guardia bajo dos condiciones: pierna dominante y no dominante. Se aplicó el análisis no lineal de Poincaré a las direcciones medio-lateral (ML) y anteroposterior (AP) y al desplazamiento total (T) del CdP, calculando los indicadores de variabilidad a corto plazo (SD1) y a largo plazo (SD2). Se empleó un ANOVA de modelo mixto con corrección de Bonferroni. Los luchadores no élite mostraron valores significativamente mayores de SD1 ($p = .018$) y SD2 ($p = .008$) en la dirección ML de la pierna dominante, sin diferencias en la dirección AP ni en el desplazamiento T. Entre piernas, los luchadores de élite difirieron en SD1 ($p = .008$) y SD2 ($p = .014$) en la dirección AP y en SD1 ($p = .025$) y SD2 ($p = .039$) del desplazamiento T. No se hallaron diferencias entre el inicio y el final de la tarea. El análisis de Poincaré resulta un procedimiento útil para monitorizar la variabilidad del CdP durante los movimientos de vaivén en lucha.

Palabras clave: Control postural dinámico; Análisis del diagrama de Poincaré; Movimientos de vaivén; Evaluación del rendimiento; Lucha.

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Comparação da variabilidade do deslocamento do centro de pressão entre lutadores de elite e não elite durante uma tarefa de posição de guarda

RESUMO

Este estudo comparou a variabilidade do deslocamento do centro de pressão (CoP) entre lutadores de elite e não elite durante uma tarefa repetitiva de posição de guarda. Sessenta lutadores (30 de elite e 30 não elite) realizaram um protocolo simulado de 30 s com ciclos curtos repetitivos sob duas condições: perna dominante e não dominante. A análise não linear de Poincaré foi aplicada às direções médio-lateral e anteroposterior e ao deslocamento total do CoP, calculando-se os indicadores de variabilidade de curto prazo (SD1) e longo prazo (SD2). Foi utilizada ANOVA de modelo misto com correção de Bonferroni. Os lutadores não elite apresentaram SD1 e SD2 significativamente maiores na direção médio-lateral da perna dominante, sem diferenças na direção anteroposterior ou no deslocamento total. Entre as pernas, os lutadores de elite apresentaram diferenças em SD1 e SD2 na direção anteroposterior e no deslocamento total. A análise de Poincaré é útil para monitorar a variabilidade do CoP durante movimentos de vaivém na luta.

Palavras-chave: Controle postural dinâmico; Análise do gráfico de Poincaré; Movimentos de vaivém; Avaliação do desempenho; Luta.

Introduction

Wrestling is a high-intensity, short-interval combat sport in which repetitive back-and-forth movements for explosive attacks and counterattacks are performed¹. Wrestler must have a stable stance throughout a match to perform these repetitive back-and-forth movements. A stable wrestling stance must be both offensive and defensive in nature². Hence, an elite wrestler is expected to demonstrate high levels of static and dynamic balance during wrestling stances³. Studies examining postural control in specific motor skills showed that postural function reflects the sport performance level of athletes (elite, sub-elite, and non-elite)^{4,5}. However, it has not been established that there is a close relationship between sports competition and postural skill level within repetitive tasks in dynamic conditions.

In wrestling, there is a tendency to use a specific leg during repetitive back-and-forth movements. This tendency may lead to asymmetries and trends of lateralisation during the match. It has been shown that the dominant and non-dominant leg asymmetries can exhibit differences in consequence of sporting activity^{6,7,8}. For example, Bailey⁶ reported negative correlations between the peak force symmetry index and all jump variables (e.g., jump height and peak power), indicating that as asymmetry increases jump performance decreases. To our knowledge, only one study has assessed biomechanical differences between the dominant and non-dominant legs during back-and-forth movements while participants performed repetitive lower-limb tasks⁹. Results revealed no significant difference between the dominant and non-dominant leg in all joint angle variables during both steps forward lunge and jump forward lunge. Accordingly, it is necessary to gain more insight into the biomechanical differences between the dominant and non-dominant legs and into postural control during repetitive back-and-forth movements.

One of the most used methods for assessing body postural control and fall risks in sports skills is the centre of pressure (CoP) movement variability. Although the existing literature provides information that helps us better understand the relationship between the CoP movement variability and the postural control system, few studies have examined the CoP movement variability in repetitive back-and-forth tasks^{10,11,12,13}. For example, a recent investigation by Cantù¹⁰ examined the effect of additional load placed on the trunk on the posture and movement adaptations to fatigue induced by performing a repetitive arm movement (pointing) task. Their findings suggested that fatigue significantly increased reach-to-reach variability in the CoP displacement. In contrast, in performing a repetitive reaching task, Fuller¹² reported that the reach-to-reach

variability of the CoP position was not affected by fatigue. These studies investigated the effect of fatigue induced by repetitive arm tasks on CoP displacement in both ML and AP directions. In contrast, it is unknown to what extent the repetitive leg tasks would develop strategies that jeopardise postural body control in back-and-forth movements.

In studies examining postural control based on the CoP displacement trajectories, linear measures of variability (e.g., statistics of range, standard deviation, and coefficient of variation) are often used. Linear measures provide information about a signal's amplitude and dispersion, but they do not tell us about the time-evolving nature of the signal¹⁴. In contrast, non-linear measures described temporal variations in motor behaviour over time. In the literature, multiple methods exist for exploring non-linear time series analysis (e.g., Lyapunov exponent, fractal, symbolic dynamics measures, Poincaré plot, and approximate entropy). Nonlinear Poincaré analyses (also called return maps) are applied to assess the short-term and long-term spatial-temporal variability during each trial¹⁵. In this method, each measurement result in data points is plotted as a function of a previous one¹⁶. Generally, Poincaré analyses have been most commonly used in heart rate research^{17,18} and their application as a measure of kinematic and kinetic time-series patterns is limited^{19,15,20}.

Therefore, the primary purpose of this study was to examine the CoP movement variability via non-linear Poincaré analyses between elite and non-elite wrestlers during short-cycle repetitive wrestling stance tasks. Accordingly, we hypothesised that non-elite wrestlers would have an increased variability in CoP displacement compared to elite wrestlers during wrestling stance tasks. Moreover, we aimed to compare the CoP movement variability between the dominant and non-dominant leg during the wrestling stance task. Hence, it was hypothesised that no significant difference occurred in the CoP movement variability between both legs.

Methodology

Participants

We recruited 30 elite (age: 18.73 ± 4.48 years, body mass: 69.56 ± 15.50 kg, height: 171.67 ± 8.74 cm, body mass index: 23.38 ± 3.86 kg/m²) and 30 non-elite (age: 14.27 ± 3.43 years, body mass: 57.32 ± 16.88 kg, height: 161.25 ± 15.91 cm, body mass index: 21.53 ± 3.72 kg/m²) male wrestlers for this study. The elite group trained six days a week involving considerable skill and fitness sessions (up to 10 per week, 60-90 minutes per session), and they played in one-two competitive games per six months. The non-elite

group trained up to three days a week, mainly in educational-type exercise workouts (3 sessions weekly, 45-60 minutes per session), but none were professional or full-time athletes. Wrestlers reporting any abnormalities (e.g., due to orthopaedic injury) that may impact balance control were excluded from participation. All participants gave their written informed consent before beginning the trials.

Procedure

A schematic representation of the protocol is shown in Figure 1. In this study, two groups of wrestlers (elite and non-elite) performed a simulated 30s protocol that involved a short-cycle, repetitive wrestling-stance task. This task was utilized to measure physical performance capacities related to balance control and change of direction ability.

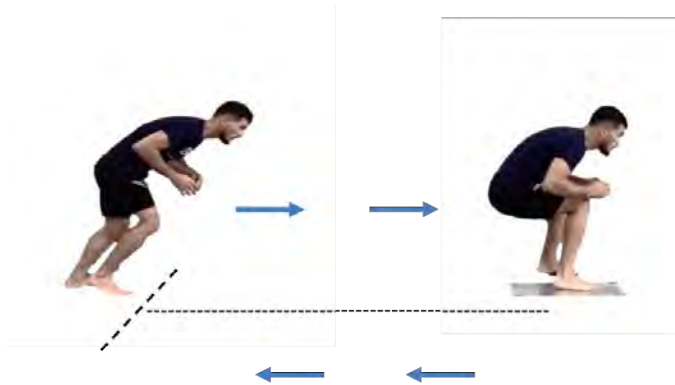


Figure 1. Schematic diagram of a wrestling stance position from the starting position (left) to the ending position (right).

Each wrestler had a practice session of two minutes or until the participant felt familiar with the task. Then, they performed the repetitive tasks of wrestling stance with five-minute breaks in between. Wrestlers began the task in the start line with the wrestling stance position; then, upon an auditory signal, they moved to a force plate, touched the force plate with their leg in the wrestling stance position and returned to the start line, touching down on the start line with their leg again. They then moved to the force plate and back to the start line until 30 s of the task had been completed. Wrestlers were required to move back and forth on a 130cm course (from the centre point of the force plate to the start line) under two conditions: dominant and non-dominant leg (without shoes). The dominant leg was defined by asking a wrestler to kick a ball²¹. Three trials were performed on the dominant leg; the wrestlers changed leg position and repeated the task on the non-dominant leg. The average of the three trials on each leg was used for subsequent analyses.

An expert observed wrestlers to ensure that appropriate pace and trunk posture were maintained during the task. None showed or expressed difficulty keeping the required pace, and all wrestlers completed the 30 s task. Wrestlers were instructed to ignore any errors and proceed to the next one.

Data analysis

The CoP position was calculated using the ground reaction forces by a Kistler force plate (Kistler Instrument AG, Winterthur, Switzerland) at a sampling frequency of 1000 Hz. The raw data were digitally filtered using a fourth-order Butterworth filter with a low-pass cutoff frequency of 15 Hz. Wrestling stance events of the foot-strike and foot-off were identified using a threshold of 10 N on the vertical ground reaction force. Then, each cycle was interpolated to 100 data points using the spline method. The number of cycles

for each trial varied depending on a sports performance level but averaged 17 cycles.

The equations used to calculate the medial-lateral (ML) and anterior-posterior (AP) CoP coordinates in the force plate were considered for further analysis. For each subject, instantaneous displacement (D_i) in the ML and AP directions and the total (T) displacement of CoP movement was calculated as follows (Bizovska et al., 2014):

$$D_{iML} = |ML_i - ML_{i-1}| \quad (1)$$

$$D_{iAP} = |AP_i - AP_{i-1}| \quad (2)$$

$$D_{iT} = \sqrt{D_{iML}^2 + D_{iAP}^2} \quad (3)$$

Where, AP_i and ML_i are i -th sample-time of the CoP one dimensional time series in the anterior-posterior and medial-lateral directions, respectively. Then, to evaluate the nature of the variability present in the D_{iML} , D_{iAP} and D_{iT} (Figure 2), Poincaré plot analysis (a nonlinear method) was used to calculate short- and long-term variability during each trial as follows¹⁶:

$$SD1 = \frac{\sqrt{2}}{2} SD(x_n - x_{n+1}) \quad (4)$$

$$SD2 = \sqrt{2SD(x_n)^2 - \frac{1}{2}SD(x_n - x_{n-1})^2} \quad (5)$$

SD is the time series' standard deviation, SD1 represents short-term, and SD2 indicates long-term variability. The SD1 and SD2 were determined within each cycle and considered variables describing CoP movement variability.

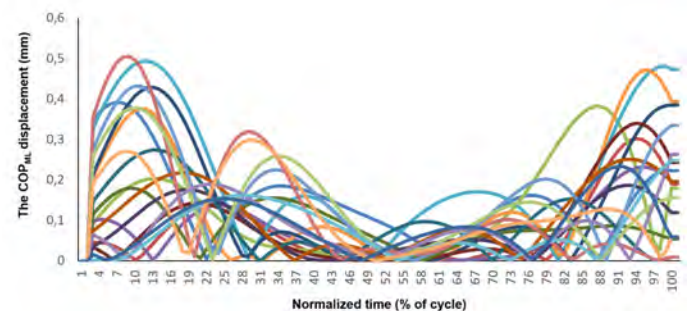


Figure 2. Example of the evaluation of inter-cycle variability from the normalised cycle.

To measure the effect of activity duration on CoP oscillations, each trial performed by subjects was split into three equal time intervals based on the execution order (beginning, middle and end). The mean of three successive cycles calculates each time interval. Finally, the mean value of the ML and AP directions and T displacement of CoP movement into three-time intervals were determined.

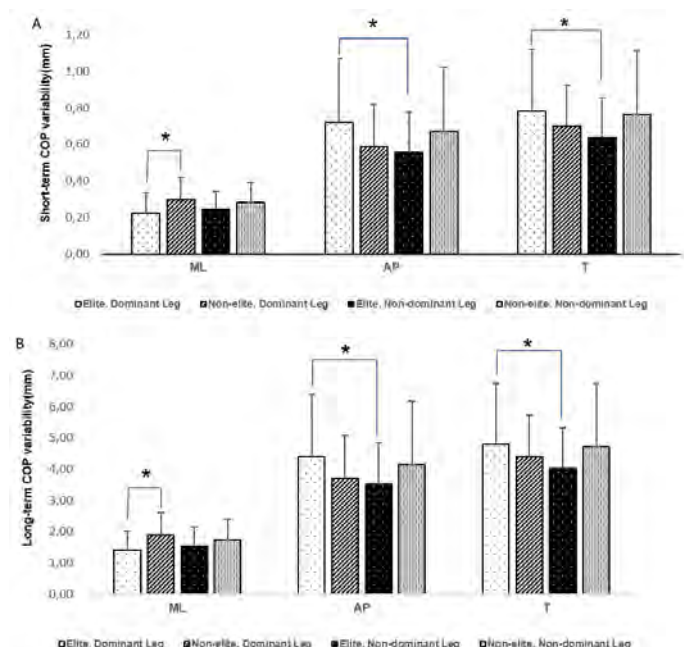
Generally, our study variables were calculated separately for the dominant and non-dominant leg. All calculations were performed using custom-written Matlab programs (MATLAB R2014b, Mathworks, Inc., Natick, MA, USA).

Statistical analysis

The mean values of SD1 and SD2 in the ML and AP directions and T displacement of CoP movement were examined using a mixed-model ANOVA (2 groups $\times$ 2 legs $\times$ 3-time intervals) to determine if significant differences occurred in three-time intervals. A pairwise comparison with a Bonferroni correction was used if any significant main effects were found for group, leg, or time interval. A mixed-model ANOVA (2 groups $\times$ 2 legs) was also used to determine differences between groups and legs for each dependent variable based on the overall average obtained by each trail for all cycles. Differences were considered significant at $p < .05$.

Results

Figure 3 shows the mean values of SD1 and SD2 of CoP movement under the dominant and non-dominant leg conditions between elite and non-elite wrestlers. A comparison of the groups revealed significant differences in mean values of SD1 ($p = .018$) and SD2 ($p = .008$) in the ML direction of CoP movement in the dominant leg. However, no significant difference was found between the two groups in the AP direction and T displacement of CoP movement. In comparison between the dominant and non-dominant leg, no significant difference was found in the mean values of SD1 and SD2 variables in the ML and AP directions and T displacement of CoP movement in non-elite wrestlers. In contrast, elite wrestlers showed a significant difference in mean values of SD1 ($p = .008$) and SD2 ($p = .014$) in AP direction and SD1 ($p = .025$) and SD2 ($p = .039$) in T displacement of CoP movement.



Abbreviations: ML (AP) – COP displacement in the mediolateral (anterior-posterior) direction, T: total COP displacement

Figure 3. The mean values and standard deviations of short-term, A, and long-term, B, variabilities of COP movement in two groups: elite and non-elite wrestlers, under two conditions: dominant and non-dominant legs. * = significant difference between groups ($p < .05$).

Finally, comparing the beginning and end times of the wrestling stance task, the result showed no significant difference in mean

values of ML and AP directions and T displacement of CoP movement in the two groups (Figure 4).

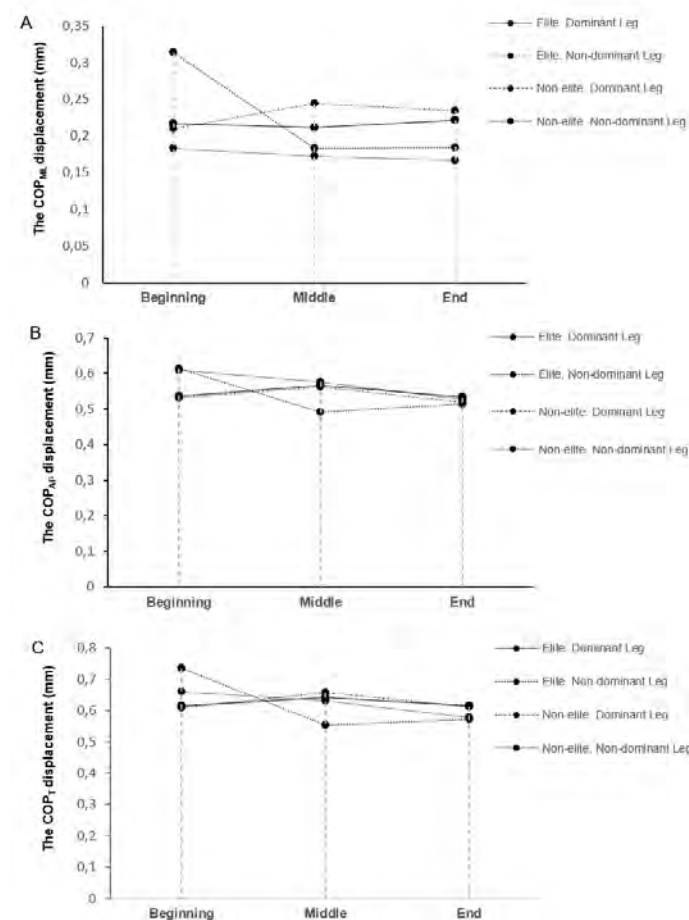


Figure 4. The mean values of mediolateral (ML), A, and anterior-posterior (AP), B, directions and the total (T), C, of displacement COP movement in two groups: elite and non-elite wrestlers under two conditions: dominant and non-dominant legs for the three-time intervals (beginning, middle, and end). * = significant difference between groups ($p < .05$).

Discussion

To our knowledge, no study has examined the variability of CoP movement during wrestling stance. Thus, we conducted this study to investigate the variability of CoP movement between elite and non-elite wrestlers during wrestling stance tasks. In this experiment, we define variability as SD1 and SD2 changes in the ML and AP directions and T displacement CoP movement. SD1 reflects the cycle-to-cycle variability in CoP movement, whereas SD2 is the continuous variability over the trial when cycle-to-cycle variability is removed²². Nestico¹⁵ reported that SD1 might reflect reactive balance control, whereas SD2 might be more indicative of an anticipatory balance control strategy. However, although the role of intra-individual variability has been analysed^{23,24}, previous studies have reported that a low variability in many sports situations is considered an indicator of improved performance²⁵ and desirable postural performance^{26,27}. Based on these observations, we defined increased movement variability as an indicator of poor postural control and increased fall risk²⁸. Consequently, we hypothesised that non-elite wrestlers would have an increased variability in CoP displacement compared to elite wrestlers during the wrestling stance task.

In support of our hypothesis, non-elite wrestlers displayed significantly higher mean values of SD1 and SD2 of CoP movement in the ML direction compared to the elite group in the dominant leg. Our results agree with a previous study by Hopper²⁹ that demonstrated

the CoP displacements of elite dancers were smaller than those of amateur dancers and control subjects. Also, Paillard³⁰ showed that professional soccer players than amateur soccer players have smaller CoP displacements during the test of bipedal standing posture. However, no significant difference between the two groups was observed in the AP direction and T displacement of CoP movement. These results indicate that when postural control is the primary focus in back-and-forth movements, measures of AP direction and T displacement of CoP movement cannot identify differences between skill levels in the wrestling stance task³⁰. Therefore, this result suggested that the changes in the magnitude of the SD1 and SD2 of CoP movement in the ML direction can be used as a good index for assessing postural control in wrestlers of different competitive levels.

In line with our findings, studies have indicated a relationship between performance level and body balance-controlling ability. They displayed that professional athletes show better postural control than their less proficient counterparts^{23,5}. As an example, Musa³¹ attributed that the elite and medalist archers had better postural performance compared to the non-medalist and novice archers. Hence, due to continuous body position changes during a wrestling match, elite wrestlers would be expected to maintain their balance in static and dynamic conditions to not only resist falling but also to act efficiently in wrestling techniques³².

Back-and-forth movements and balance are intimately linked and inseparable in many wrestling situations. Hence, both legs' symmetrical behaviour has been assumed in evaluating these movements. In line with this assumption, our results revealed no significant difference between the dominant and non-dominant leg in the mean values of SD1 and SD2 in the ML and AP directions and T displacement of CoP movement in non-elite wrestlers. Our findings are consistent with previous research^{33,34}. In contrast, elite wrestlers showed significantly higher mean values of SD1 and SD2 in the AP direction and T displacement of CoP movement in the dominant leg than in the non-dominant leg. This increased variability in the dominant leg may reflect the flexibility in adapting to perturbations³⁵. This finding is consistent with previous reports showing greater AP and vertical oscillations of pistol tremor with no difference in ML direction^{36,37}. As a result, understanding both variability and symmetry in the dominant and non-dominant leg during the back-and-forth movements can assist coaches in developing movement strategies and maintaining postural balance.

Researchers have long debated whether performance in sports skills changes over time. Accordingly, there are two basic approaches to measures of within-person performance variability over time³⁸. The first is short-timeframe variability relevant to the variation in performance in short periods (e.g., seconds, minutes, hours, or days)^{39,40}. The second is long-timeframe variability, which attempts to answer whether performance is static or variable over long periods (e.g., months, years, or decades)^{41,42}. Considering the importance of critical moments in wrestling, evaluating a wrestler's performance from occasion to occasion over short periods could improve our understanding of the factors involved in body postural control. Hence, we assessed the effect of execution duration (beginning, middle, and end) on the variability of CoP movement during the wrestling stance task. Our results showed that execution duration did not affect the variability of any ML and AP directions and T displacement of CoP movement analysed parameters. This is consistent with the previous finding by Roberts⁴³, who reported no change in the variability of CoP displacement in the ML direction during quiet stance trials. However, they reported that the AP CoP displacement was greater during the 5% and 10% compared to the 0% load. Generally, the outcomes of our research showed that the mean value of ML and AP directions and T displacement of CoP movement remained relatively stable over time in non-elite wrestlers than in elite wrestlers (Figure 4), which contradicts our hypothesis.

Limitations and future directions

This study, which aims to understand postural control, has some limitations. First, it analyzed only the role of center of pressure (CoP) variability in postural control. Future studies should examine the role of center of mass (COM) variability during postural tasks in wrestling. A second limitation is that we analyzed time-series data using a nonlinear method that requires mathematical programming techniques to assess performance variability, which is primarily calculated in a research setting¹⁴. Therefore, it is necessary to design devices with integrated software to assess postural control using nonlinear methods in natural training and competition settings. Finally, there is a lack of any analysis of postural control during repetitive forward and backward leg movements over short periods (e.g., seconds, minutes).

Conclusions

In the present study, the non-linear Poincaré analysis method was used to determine the CoP movement variability between elite and non-elite wrestlers during the wrestling stance task. The results suggested that the Poincaré analysis can provide a useful method for measuring CoP movement variability during back-and-forth movements when the wrestlers are being monitored. Moreover, the findings above demonstrate that quantifying performance variability in repetitive wrestling-stance tasks can provide insights into wrestlers' ability to maintain postural control during training and competition.

Conflict of interest

The authors declare that they have no conflict of interest, financial or otherwise, regarding the material discussed in this manuscript.

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Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki. All participants, and the legal guardians of participants under 18 years of age, gave written informed consent before the trials.

Author contributions

Conceptualisation: M.A., M.E.; methodology: M.A., M.E.; formal analysis: M.A., J.P.; investigation: M.A.; data curation: J.P., D.R.-V.; writing – original draft: M.A., J.P.; writing – review and editing: M.E., D.R.-V.; supervision: M.E., D.R.-V. All authors have read and approved the final version of the manuscript.

Data availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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