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ORIGINAL ARTICLE

A comparison of the ground reaction forces of archers with different levels of expertise during the arrow shooting

Comparaison des forces de réaction au sol d'archers de différents niveaux d'expertise pendant le tir de flèches

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KEYWORDS
Center of pressures;
Reaction forces;
Postural control;
Archery

Summary
Objective. — The purpose of this study was to compare the differences in ground reaction forces (GRFs) of archers with different levels of expertise during arrow shooting.
Material and methods. — Twenty-seven male archers were involved in this study. Anterior-posterior ground reaction force (APGRF-Fy) and medio-lateral ground reaction force (MLGRF-Fx) collected by force platform during the successful shots towards the target from a distance of 18 m. The center of pressure (CoP) excursion was computed during arrow shooting using the GRFs. All statistical analyses were completed using SPSS 22.0 for Windows software (SPSS Inc., Chicago, IL). The level of statistical significance was set as $P < 0.05$.
Results. — Results demonstrated that elite group had the least CoP sway, APGRF and MLGRF during all phases comparing to both mid-level, beginner level archers. However the differences in APGRF and MLGRF between groups didn't reach the significance level ($P > 0.05$). The sway range of CoP values of elite group were significantly smaller than the values of beginner group ($P < 0.05$).
Conclusion. — In conclusion, it was observed that the relationship between body sway and expertise level. Therefore instantaneous visual force feedback training including APGRF, MLGRF and CoP sway values could be recommended in order to increase shooting performance.

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MOTS CLÉS
Centre des pressions ;
Force de réaction ;
Contrôle postural ;
Tir à l'arc

Résumé
Objectif. — L'objet de la présente étude était de comparer les différences dans les forces de réaction au sol (FRS) d'archers de différents niveaux d'expertise durant le tir de flèches.
Matériel et méthodes. — Vingt-sept archers masculins ont participé à cette étude. Les forces de réactions au sol antérieure-postérieure (FRSAP-Fy) et médio-latérale (FRSML-Fx) ont été enregistrées sur une plate-forme de force durant les tirs réussis vers la cible à une distance de 18 m. L'impact sur le centre de pression (CdP) a été mesuré par ordinateur durant le tir des flèches en utilisant les FRS. Toutes les analyses statistiques furent réalisées avec le logiciel SPSS 22.0 pour Windows (SPSS Inc., Chicago, IL). L'analyse de variance à un facteur (ANOVA) a été utilisée pour identifier les différences significatives au sein des groupes.
Résultats. — Les résultats indiquent que le groupe d'archers élites présentait le CdP, la FRSAP et la FRSML les plus faibles durant toutes les phases, comparativement aux archers de niveaux intermédiaire et débutant. Cependant, la FRSAP et la FRSML entre les groupes n'ont pas fait apparaître les différences significatives ($p > 0{,}05$). Par ailleurs, la variabilité du CdP dans le groupe élite était significativement moins importante que dans le groupe de débutants ($p < 0{,}05$).
Conclusion. — Les résultats de cette étude montrent que le niveau d'expertise sportive augmente lorsque l'oscillation du corps diminue. Par conséquent un entraînement au retour de force visuel instantané comprenant les valeurs d'impact des FRSAP, FRSML et CdP peut être recommandé afin d'accroître les performances de tir.

1. Introduction

The upright posture is important for human motor abilities and its control is an essential requirement for physical activities in daily life. Postural control is a particularly complex system that involves the integration of various sensory and motor components. The information from the three sensory systems (visual, vestibular and proprioceptive) has a considerable role in standing balance [1,2]. The different sport disciplines require the different degree of postural stability and create the specific balance control strategies for keeping equilibrium [3]. Archery is a static sport, where high postural stability, coordination of the body segments and high concentration of attention at the time of shot execution are most important to achieve high scores [4]. High performance shooting in archery is defined as the ability to shoot an arrow at a given target with accuracy [5]. Getting the high score in archery requires the talent of maintaining center of gravity which is called ''postural control'' gained by fighting against the forces sabotaging the balance of the body [6]. Postural control is usually assessed by interpretation of parameters derived from the centre of pressure (COP) such as velocity and area of COP displacement [7]. COP is defined as the point of application of ground reaction forces under the feet.

Stability of postural control and balance is essential for elite athletes in order to reach peak performance. It can be described as a static sport requiring:

- balance;
- fine movement control;
- proper endurance and;
- strength of the upper body [8].

The discipline involves a three-phase movement (stance, drawing and aiming). Nishizono et al. (1987) divided the movement further into six phases: bow hold, drawing, full draw, aiming, release and follow-through [9]. An archer's skill is evidenced in the ability to shoot the arrow to the specific target within a specific time. To achieve this, athletes need to minimize their movements in each step or phase to avoid unnecessary movements which can reduce stability, thus, minimizing the chances of hitting the centre of a target. An archer's movements must be as precise as possible, coping fast with postural instability [10—13].

One of the key elements to obtain better stability in archery is to have a good stance and posture. The term stance specifically refers to the standing posture of the archer. Stance requires strength in the legs, and the right stance can help to maintain stability while standing for an extended period [14]. In archery, once the archer has aimed and fixed their posture, the fluctuations of the body must be regulated such that the alignment of the arrow remains within the target boundary, and the individual's centre of gravity (COG) within their base of support (BOS) [8,15]. Therefore, the release phase must be well-balanced and highly reproducible to achieve commendable results in an archery competition [14]. An archer pushes the bow with an extended arm held statically in the direction of the target, while the other arm dynamically pulls the bowstring from the beginning of the drawing phase until the release is dynamically executed [16]. The release phase must be well-balanced and highly reproducible for the archer to achieve commendable results in a competition [9]. The bowstring is released when an audible impulse is received from the ''clicker'' a device used to check the draw length [16]. Using this device, each arrow can be drawn to an exact distance, and a standard release can be obtained. The clicker is reputed to improve the archer's score and is used by all target archers. The archer is not able to control the drawing length and weight of the bow if s/he does not respond to the clicker stimulus as quickly as possible. Loss of control

Table 1 Means and standard deviations of FITA scores, years of archery experience, age, height, drawing weight and reaction time of the subjects.

Groups	Years of training	Age	Height	Body weight (kg)	FITA scores	Drawing weight (kg)	Reaction time (ms)
(*n*)	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
BA (*n* = 9)	1.4 ± 0.5	22.6 ± 6.0	176.5 ± 4.9	72.1 ± 17.2	915.2 ± 15.9	34.8 ± 2.8	167.2 ± 16.9
MLA (*n* = 9)	6.6 ± 3.3	23.8 ± 7.6	176.1 ± 9.1	71.6 ± 19.0	1150.3 ± 12.0	35.5 ± 3.9	140.0 ± 11.9
EA (*n* = 9)	8.7 ± 4.9	25.5 ± 8.3	178.6 ± 6.0	78.5 ± 11.5	1244.5 ± 40.7	44.0 ± 1.4	111.6 ± 9.2

of the arrow's drawing length and the weight of the bow result in differences in the release weight of the bowstring and the flying velocity of the arrow. Thus, the speed of the reaction to the fall (sound) of the clicker is directly related to the archer's performance [17]. Thus, reaction time (RT), which is the interval between the stimulus and the response initiation, is used to classify archers as elite, mid-level or beginner [18—21]. Archer's expertise also plays a major role in determining whether they are able to cope with postural stability.

The different levels achieved by archers represent different styles of stance and different weight distribution, which depends on the height, bone structure and body posture. The body posture functions as a reference framework for movements. It provides the head, torso, hip, legs and other body segments a framework for moving towards any specific target or performing any movement [13,22]. In normal standing positions, the main function of the postural control system is to integrate the antigravity and balance functions of the body. Postural control (PC) ability is related to skill level for archers, with the more proficient archers displaying greater balance ability just prior to the arrow shot [23]. In other words, to sustain aiming stability at the highest level, elite archers displaying optimal postural stability whilst controlling every other aspect in their aiming prior to the shoot.

Earlier research illustrated that postural stability also plays a major role in determining performance [24—26]. These studies allow comment to be made on balance ability raised by researchers investigating mechanisms underpinning archery shooting. On the other hand the limited amount of these biomechanical researches in shooting has focused on the influence of body sway and aim point fluctuation on performance [14,27—31]. These studies have been performed by using low number of subject and mostly focused on only two levels (senior and junior or expert and novice). No study has ever quantified the relationship between body sway during release stage in terms of expertise level (beginner, mid-level and elite). Additionally, previous studies have mostly focused on one phase wherein the overall data were compared between groups. In this study, it was possible to determine the phases (full draw, aiming, release and follow-through) that most significantly impacted shooting performance, rather than looking at the process generally. The purpose of this study was to evaluate differences in GRFs and CoP sway of the Olympic-style archers with different levels of expertise during arrow shooting phases. This study hypothesized that archers with different levels of expertise could make different use of GRFs and CoP sway, during the arrow shooting, and that the elite archers could generate more effective force transfer than the sub-elite archers.

2. Methods

2.1. Subjects

Twenty-seven male archers (elite archers, EA: *n* = 9; mid-level archers, MLA: *n* = 9, beginner archers, BA: *n* = 9) volunteered to participate to the current study. The archery level have divided into three groups (elite archers > 1150, mid-level 1100—1150, beginner archers < 1100) according to their FITA scores. Archers are considered skilled (elite) due to their qualification scores of 1150 upon 1440 full FITA score in either national or international rank competitions. All archers were right-handed and recurve bows were used in this study. Their descriptive statistics are summarized in Table 1. All subjects were without any orthopedic or neurological problems, articular and muscle trauma or injury in the past 6 months.

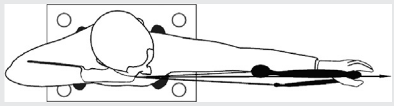
The study was approved by the University of Osman Gazi Human Research Ethics Board (2008/508), and subjects provided their informed written consent prior to participation. All subjects were volunteers and they were free to withdraw from the study at any time.

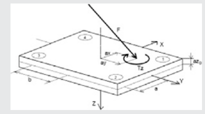
2.2. Procedures

This investigation used an experimental design to compare the differences in GRFs of archers with different levels of expertise during arrow shooting. Dependents (response) variables were CoP sway, APGRF and MLGRF. Subjects attended the Performance Laboratory at Anadolu University for familiarization and tests for two days. On the first visit, anthropometric measurements were completed and force platform familiarization was performed by subjects. Data collection was completed with the following order in the second visit:

- before starting the test session, the participants performed a 15 minutes standardised warm-up consisting of 5 minutes of active upper body movement, 5 minutes of upper body stretching and 5 minutes of arrow shooting for short distance targets;
- all of the archers were tested for short distance (18 m which is an official competition indoor distance) shootings in the archery field.

Table 2 Force plate calculation formulas.





Output Signal	Channel	Description
fx12	1	Force in X-direction measured by sensor 1 + sensor 2
fx34	2	Force in X-direction measured by sensor 3 + sensor 4
fy14	3	Force in Y-direction measured by sensor 1 + sensor 4
fy23	4	Force in Y-direction measured by sensor 2 + sensor 3
fz1...fz4	5...8	Force in Z direction measured by sensor 1...4

Parameter	Calculation	Description
Fx	= fx12 + fx34	Medio-lateral force
Fy	= fy14 + fy23	Anterior-posterior force
Fz	= fz1 + fz2 + fz3 + fz4	Vertical force
Mx	= b × (fz1 + fz2 − fz3 − fz4)	Plate moment about X-axis[3]
My	= a × (−fz1 + fz2 + fz3 − fz4)	Plate moment about Y-axis[3]
	= b × (−fx12 + fx34) + a × (fy14 − fy23)	Plate moment about Z-axis[3]
Mx1	= Mx + Fy × az0	Plate moment about top plate surface[2]
Ax	= − Myı/Fz	X-coordinate point of applied force (CoP)[2]
Ay	= Mxı/Fz	Y-coordinate point of applied force (CoP)[2]

Shooting cue was given by either the researchers. The target face used was the official FITA 40 cm 18 meter target. Participants were asked to use their own bow and arrows to ensure participant's own shooting style and shooting performance. The participants were allowed to shoot with their preferred position but stance techniques were limited as they were required to use the straight stance. The participants were asked to stand still with full equipment on the shooting line for 10 seconds to obtain a standing-upright posture value. Whenever the participants were in the stance phase, they were given a ''start'' command and the data was collected.

2.2.1. Ground reaction force measurements

The subject's weight and height were measured before starting the experiment. The force data of aiming, drawing, full drawing, releasing and follow-through phases of archery were recorded using force platform (Kistler 9281EA, Germany). A high-speed MotionBLITZ EoSens® Cube7 video cameras (MIKROTRON, Germany) was placed perpendicular to the lateral side of the archers to identify postural sways during releasing, and the data were collected at 500 frames per second. A mechanical switch with a flashing LED light was placed on the clicker to accurately measure when the clicker makes contact with the bow. Just as the clicker snapped, the LED light hanging on the archer's belt flashed and simultaneously sent a ± 5 V TTL signal to the force platform system. In this way, the system was synchronised and referenced to the clicker fall. The centre of the target was placed directly in line with the midline drawn parallel to the short axis of the platform so that the Fy direction represented APGRF and the Fx direction represented MLGRF. Total postural sway in each direction was measured by analysing the total excursion of the CoP during the shot. Archers were asked to do their best to hit 10 points to the 18 meters target with no time limitation. During the successful shots towards the target from a distance of 18 m were analysed the APGRF, MLGRF and CoP sway values. Force data sampled at 2000 Hz and normalized according to body weight. Data calculation formulas are given in Table 2.

2.3. Statistical analyses

Data were expressed as mean ± standard deviation (X ± SD). Normality and homogeneity of variances of the data were confirmed by the Kolmogorov-Smirnov and the Levene tests, respectively. Descriptive statistics were applied to identify the characteristics of the subjects and the groups. A one-way analysis of variance (one-way ANOVA) was conducted to compare GRFs (Fx and Fy) and CoP sway values during each time interval among archery groups. ANOVA was followed by Tukey PostHoc comparisons to determine the intervals where significant differences did occur. An alpha of 0.05 was used for all statistical tests, which were performed using SPSS version 22.0 (SPSS Inc, Chicago, Illinois).

3. Results

The average of Fx and Fy GRFs values and reaction times (EA: 111.64 ± 9.20 ms; MLA: 140 ± 11.98 ms; NA: 167.22 ± 16.98 ms) of archers with different levels of expertise are displayed in Fig. 1

. Fig. 2 shows the average data and individual values around the mean data of sway (mm) in anteroposterior (Ay) and medio-lateral (Ax) axes of the CoP of the archers with different levels of expertise, during the whole shooting phase.

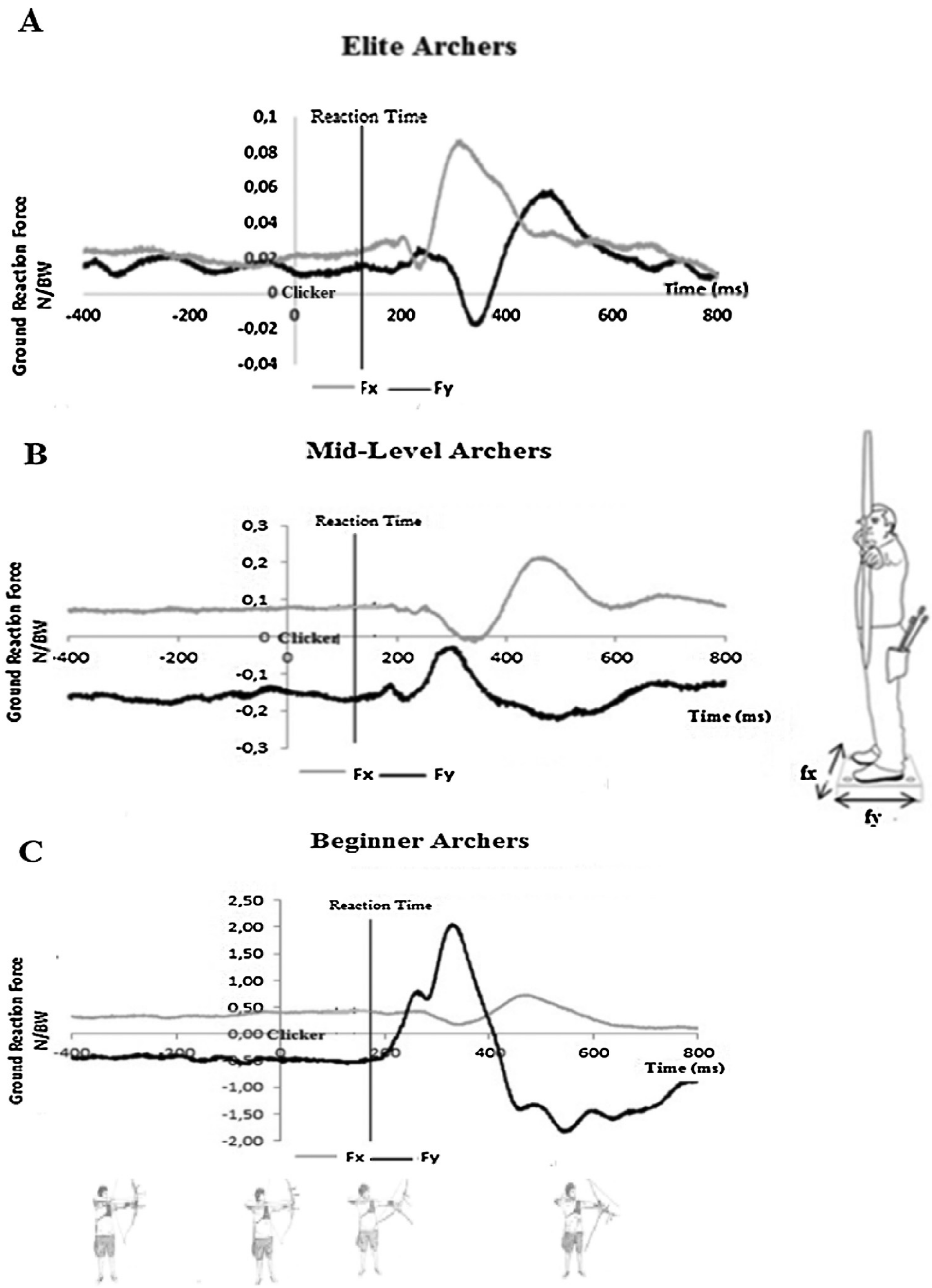


Figure 1 The average GRF values (expressed as a percentage of body weight, BW) in the Fx and Fy axis of elite, mid-level and beginner archery groups during arrow shooting phases. A. Shows Fx and Fy GRFs for elite archers during arrow shooting phases (phases: drawing, full draw, aiming, release and follow-through). The least sway range recorded was during the draw and full draw and the highest sway range occurred just after the snap of the clicker. During the draw and full draw phases, the sway on Fy and Fx directions were positive which indicates the occurrence of swaying to the anterior comparing to posterior and the weight distribution is more on the right foot than the left foot, respectively. In the aiming stage, the archers try to stabilize their weight distribution in a short period. However, just after the arrow is released, Fx data indicates that the weight acting on the right foot is sharply reduced and weight on the left foot increased for a brief instant. The weight change indicates that the weight distribution acting on the archer's left foot is reduced during the follow-through phase. During follow-through stage, the Fx data indicates that weight is acting on the right foot again. The Fy data trend clearly shows that the elite archers were in the process to move to the center line as evidenced from the decreasing value of postural sway after the snap of the clicker to the release phase. B. Shows Fx and Fy GRFs for mid-level archers during arrow shooting phases (phases: drawing, full draw, aiming, release and follow-through). The least sway range recorded was during the draw and full draw and the highest sway range occurred just after the snap of the clicker. During the draw and full draw phases, the sway on Fy direction was negative which indicates the occurrence of swaying to the posterior. In addition, the sway on Fx direction was positive which indicates the weight distribution is more on the right foot

The Fig. 1 shows totally 1200 ms minus 400 up to plus 800, zero corresponds with the snap of the clicker. Before and just after the snap of the clicker, all of the subject groups demonstrated almost same sway strategy but the elite archers have less GRFs on Fx and Fy directions. However the GRFs for Fx and Fy didn't reach the significance level ($P > 0.05$). The sway range of CoP values of elite group were significantly smaller than the values of beginner group ($P < 0.05$) (Fig. 2).

4. Discussion

The purpose of this study was to compare the differences in ground reaction forces (GRFs) of archers with different levels of expertise during arrow shooting phases. This study hypothesized that archers with different levels of expertise could make different use of GRFs and CoP sway, during the arrow shooting, and that the elite archers could generate more effective force transfer than the sub-elite archers.

Mason and Pelgrim (1986) have analysed balance ability and shooting accuracy on force platform by testing CoP sway. They compared the body sway a few seconds before shooting with CoP change rates, CoP standard deviation, and anterio-posterior side CoP speed and medio-lateral side CoP speed in their study. They concluded their results as balance ability was associated with shooting accuracy for juniors and less experienced ($r = 0.51$), but not for seniors or more experienced archers. The senior archers had superior balance ability when compared with junior archers; a high level of stability is a prerequisite to becoming an elite archer and, at this level of expertise, the range of postural sway is small and was not an important discriminating factor for elite senior archers [24]. Stuart and Atha (1990) performed a study on 10 male elite archers and found similar results with Mason and Pelgrim (1986) [24,26] data set. This result indicated that precise postural consistency may not be the primary feature distinguishing between the performances of archers at the higher skill levels. Findings of Era et al. (1996), Monenen et al. (2007), Stuart et al. (1990) reveal parallelism with the results of the research of Mason and Pelgrim (1986) [24,26,32,25]. In line with previous studies, Tınazcı (2011) analysed relationship between balance ability and performance measures on 4 male elite archers by focusing on static balance, postural sway, aiming sway and body weight shifts, changes in the posture of archers toward sideways and front-back during 30 arrows to the target 18 m away. The results of Tınazcı (2011) study, aiming or sight trajectory sways on the target vertically and horizontally, and APGRF and MLGRF during release may adversely affect the resulting score. Moreover drawing time may change with performance and which is affected by shift in the body weight especially after releasing [14].

In the current study, three level groups have been analysed different than the other studies. According to results, sway range values of elite archers were observed to be lower than mid-level and beginner archers in the current study. The study findings support the hypothesis because of significantly different use of GRFs and CoP sway of elite archers, during the arrow shooting, and that the elite archers could generate more effective force transfer than the sub-elite archers.

As elite archers transpose their body weight forward before pulling the clicker, they manage to carry their strong point into the middle point. Additionally, elite archers have superior balance ability compared to mid-level and beginner archers. This implies that physical training enhances bipedal equilibrium control and reduces body oscillations. There are some sports where elite athletes have been shown to possess superior balance ability to their less proficient counterparts. International level rifle shooters had superior bipedal static balance to national level shooters who in turn were superior to novice shooters [23,32,33]. Fx and Fy sway ranges of mid-level archers are higher than the elites but lower than beginner archers. These findings reveal that the balance values of mid-level archers are possible to reach the values of elite archers through trainings. Fx and Fy values of beginner archers are higher than the previous two groups. The results of this research corroborated the previous research because archer's expertise also plays a major role in determining whether they are able to CoP with postural stability. Expert athletes are able to rapidly stabilize postural stability compared to beginner and novice athletes. According to practice-based automaticity theories, attentional demands are minimized when athletes are highly trained on postural tasks [34]. Similarly, skilled archers are highly trained in order to achieve stable aiming and good shooting performance. Clearly, athletes who are highly tuned on activities are able to minimize their intentional demands on the performance itself because it has been automated by the body system. Since the movements of expert athletes are automated rather than controlled, expert athletes are able to focus on perfecting the techniques of shooting in order to obtain stable aiming and to get consistent shooting performance [26,32,34—37] On the other hand only one study performed to compare balance ability of according to the Fédération Internationale de Tir à L'Arc (FITA) scores (FITA scores: Elite: 1210.1 ± 19.1 points; General: FITA scores: 1122.5 ± 47.3 points) (Lin et al., 2009). However, this study

than the left foot during all phases. Fx and Fy values which approaching to zero during aiming stage indicates that the archers tries to stabilize their weight distribution in a short period. During follow-through stage the weight acting on the right foot and swaying to the posterior again. C. Shows Fx and Fy GRFs for beginner archers during arrow shooting phases (phases: drawing, full draw, aiming, release and follow-through). The least sway range recorded was during the draw and full draw and the highest sway range occurred just after the snap of the clicker, similarly other groups. However the sway distribution was much higher comparing to elite and mid-level archers. During the draw and full draw phases, the sway on Fy direction was negative which indicates the occurrence of swaying to the posterior. In addition, the sway on Fx direction was positive which indicates the weight distribution is more on the right foot than the left foot during all phases. However, just after the arrow is released, the swaying occurred to the anterior. During follow-through stage the swaying occurred to the posterior again.

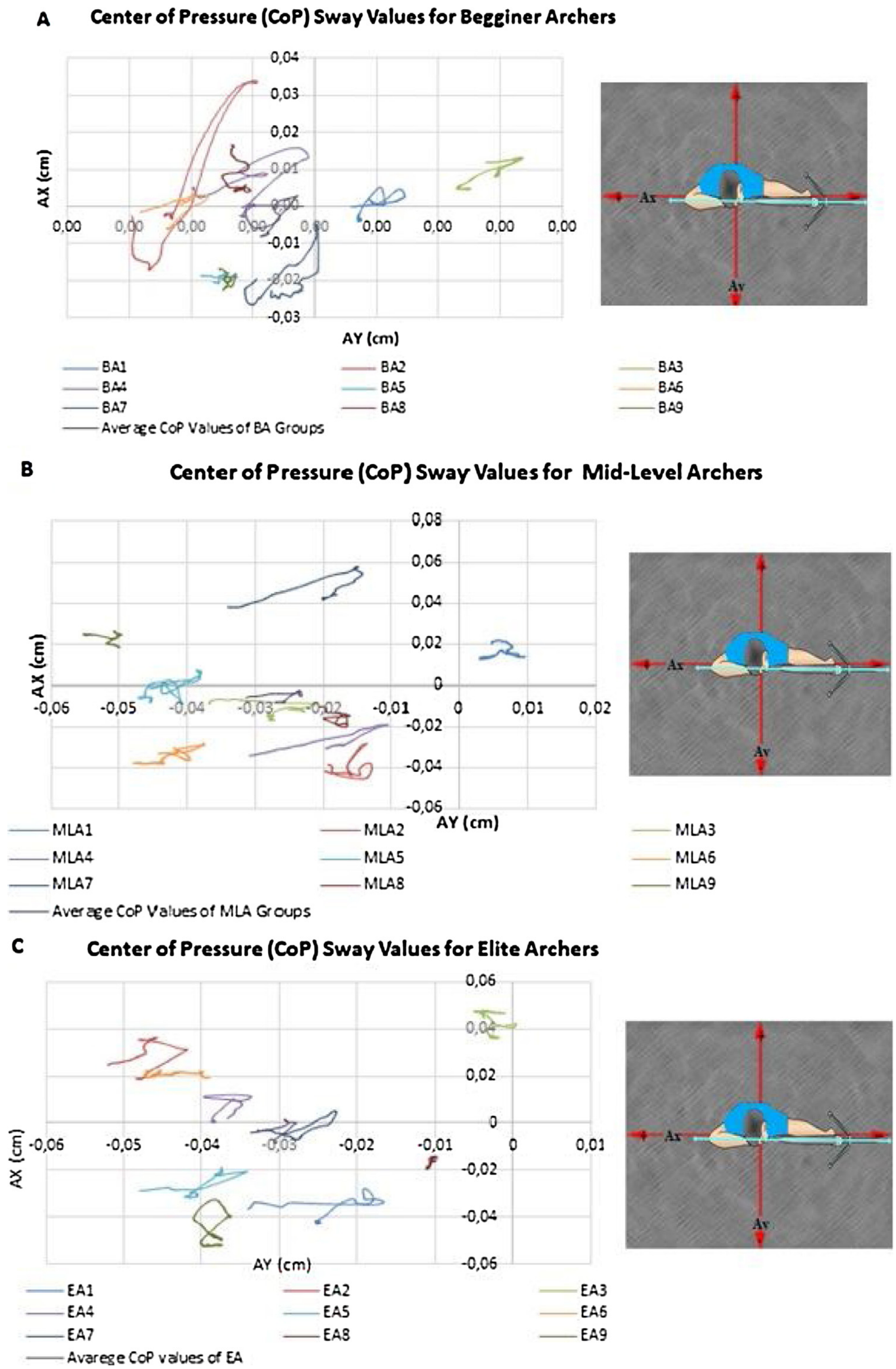


Figure 2 The average data and individual values around the mean data of sway (mm) in anteroposterior (Ay) and medio-lateral (Ax) axes of the CoP of the archers with different levels of expertise, during the whole shooting phase.

is limited with postural sway during single/double limb(s) standing while eyes are opened/close. According to data elite archers showed significant smaller CoP sway velocity and area. The CoP sway area was also significantly smaller during the better shoots determined by higher-scores.

In general, the results of these studies revealed that balance point projection of archers, in terms of the area they occupy during shooting, the elite archers showed a sway towards medio-lateral, but the amount of sway towards anteroposterior was relatively less. In addition, elite archers exibited reduced clicker reaction time and postural sway post-arrow release. The present results parallel to the findings of the study of Spratford and Campbell (2017) [38].

It was observed from current and the other study's that as the performance level decreased the movements towards front and back increased. So mid-level and beginner archers are similar in terms of postural control. This situation is thought to be a factor decreasing the score at the target. It can be derived from these results that as the archers get experienced through technical development and shooting trainings postural sway rates at Fx and Fy sides will decrease. The experienced archers were observed to manage to stabilize their postures better even at the last seconds of shooting. In addition, elit archers showed less overall limb asymmetry than mid-level and beginner archers, suggesting that elite archers use a more coordinated pattern for postural control and force management between lower limbs. The present results indicate that the systematic specific sport training of archers, including fixation of the posture and concentration upon the target, leads to stabilization of quiet upright stance, especially during stance on stable support, compared to that of mid-level and beginner archers. Future studies on appropriate training programmes, or specialized apparels and apparatus (insole system and eye tracking) for precision aiming task athletes should be conducted to minimize the effects caused by uncontrolled postural sways. Besides some evidence on an association of greater postural sway with the increasing risk of injuries, there are many myths related to the negative influence of impaired balance on sport performance [39]. In order to train archers in the case of keep balance just before arrow release instantaneous visual force feedback training including APGRF, MLGRF and CoP sway values could be recommended. Balance training may lead to task-specific neural adaptations at the spinal and supraspinal levels. It may suppress spinal reflex excitability such as the muscle stretch reflex during postural tasks which leads to less destabilizing movements and improved balance ability. Furthermore, so as to detailed investigation of postural sway at APGRF and MLGRF directions, synchronized analyses of postural muscles' activations and sway analyses should be performed in the future studies.

Disclosure of interest

The authors declare that they have no competing interest.

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