POLITECNICO DI TORINO
Repository ISTITUZIONALE

Postural sway in volleyball players

Original
Postural sway in volleyball players / Agostini, Valentina; Chiaramello, Emma; Canavese, L.; Bredariol, C.; Knaflitz, Marco. - In: HUMAN MOVEMENT SCIENCE. - ISSN 0167-9457. - STAMPA. - 32:3(2013), pp. 445-456. [10.1016/j.humov.2013.01.002]

Availability:
This version is available at: 11583/2507404 since:

Publisher:
Elsevier

Published
DOI:10.1016/j.humov.2013.01.002

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

18 April 2024

Postural sway in volleyball players

Valentina Agostini[1], Emma Chiaramello[1], Lorenzo Canavese[2], Carla Bredariol[2], Marco Knaflitz[1]

[1]Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Torino, Italy

[2]Clinica Oculistica dell'Università di Torino, Torino, Italy

Corresponding author: Valentina Agostini, Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy.

Tel: +39 011-0904136, Fax: +39 011-0904217, E-mail: valentina.agostini@polito.it

Abstract

The aim of this work was to analyze the postural sway of volleyball players in bipedal quiet stance. The center of pressure (CoP) was measured in 46 athletes and 42 non-athlete controls. Each subject was tested in 10 different conditions, 5 with their eyes open and 5 with their eyes closed. Volleyball players showed greater CoP ellipses, suggesting a different model of sensory integration in their postural stability. A multivariate approach to data analysis demonstrated that the postural sway of the two groups was different when the subjects kept their eyes open, but it was not with visual deprivation. This could partially be explained by the better 'dynamic' visual acuity of athletes, since possible ('static') refractive errors were corrected for both groups. Furthermore, we expected that national players, engaged in more intensive training programs, were more different from controls than regional ones, and that defensive players, whose role requires the quickest reaction times, were more different from controls than hitters. Our results confirmed these hypothesis.

The protocol presented might be useful to assess the efficacy of intensive sport training programs and/or to select elite players with an aptitude for a specific playing position.

Keywords: Volleyball; Postural control; Static posturography; Center of Pressure (CoP); Visual skills

1. Introduction

A skilled control of postural stability is fundamental in many of the actions performed by volleyball athletes. The effectiveness in serving, receiving, setting, or digging the ball is affected by the athlete's ability to control their dynamic balance. Volleyball players are asked to adapt their posture very quickly to promptly react to each game situation. A rapid restoration of the body balance after an equilibrium disturbance is crucial. In fact, trying to handle the ball having a poor postural stability results in far less accurate actions. Coaches are aware of the importance of balance training to improve the team's performances. Furthermore, the effectiveness of balance training in

preventing serious injuries was demonstrated in various sports (McGuine & Keene, 2006; Petersen et al., 2005; Söderman, Werner, Pietilä, Engström, & Alfredson, 2000; Verhagen et al., 2004).

The control of upright posture depends on the integration of information arising from visual, vestibular, and proprioceptive systems (Winter, 1995). Since many physiological aspects contribute to determine balance performances, evaluating postural control quantitatively may be a challenging task.

Static posturography provides an objective evaluation of postural control performances by characterizing the body sway during upright standing (Baratto, Morasso, Re, & Spada, 2002; Ruhe, Fejer, & Walker, 2010; Winter, 1995). This technique is based on the study of the Center of Pressure (CoP) trajectory of a subject in quiet standing on a force platform.

Training allows sportspeople to acquire new abilities in balance control according to the discipline practiced (Arkov et al., 2009; Gerbino, Griffin, & Zurakowski, 2007; Perrin, Deviterne, Hugel, & Perrot, 2002). Postural control investigation in athletes could provide insight into the development of specific postural strategies required by a particular sport. In literature there are studies investigating postural control in dancers (Arkov et al., 2009; Gerbino, Griffin, & Zurakowski, 2007; Golomer, Cremieux, Dupui, Isableu, & Ohlmann, 1999; Perrin, Deviterne, Hugel, & Perrot, 2002; Schmit, Regis, & Riley, 2005), gymnasts (Vuillerme et al., 2001), judokas (Perrin, Deviterne, Hugel, & Perrot, 2002), soccer (Bieć & Kuczyński, 2010) and volleyball players (Kuczyński, Rektor, & Borzucka, 2009; Dai, Sorensen, & Gillette, 2010).

In specific sports, practice may modify the influence of the visual input on balance performances. As an example, using dynamic posturography, Golomer et al. (1999) found that male professional dancers were significantly more stable and less dependent on vision for postural control than untrained subjects. They suggest that professional dance training strengthens the accuracy of proprioceptive inputs and shifts sensorimotor dominance from vision to proprioception.

Athletes practicing volleyball have a constant involvement of the visual system. This is certainly true in many team sports, but volleyball players especially are constantly making ocular

movements. Thinking about the position of the eyes that is kept by the players when playing defense (sumsumversion), one realizes how a proper functioning of ocular motility is fundamental to adequately react to the attack of the opposite team. The constant movement of the ball in the game field implies a training of the eye muscles. This “ocular training” might have an impact in postural control.

In literature there are many studies pointing out the relationship between the performances of athletes in specific disciplines and their visual skills (Golomer, Cremieux, Dupui, Isableu, & Ohlmann, 1999; Jafarzadehpur, Aazami, & Bolouri, 2007; Paillard & Noé, 2006; Piras Lobietti, & Squatrito, 2010). In fast ball-sports, dynamic visual acuity of athletes is known to be superior to that of non-athletes (Ishigaki & Miyao, 1994). In volleyball, it was demonstrated that female players show a better facility of accommodation and more saccadic eye movements than the non-playing control group (Jafarzadehpur, Aazami, & Bolouri, 2007). Another study, on a male group of volleyball players, demonstrated that expert players perform fewer fixations of longer duration, concentrating on the starting and ending points of the ball trajectory, while non-athletes tend to follow the whole trajectory (Piras, Lobietti, & Squatrito, 2010). The cited works established that vision in volleyball players differs from that of untrained subjects. Furthermore, Rougier & Garin (2007) reported that saccadic eye movements might modify postural control in keeping the upright standing position.

In this study we examine the body sway during bipedal upright stance of volleyball athletes and non-athlete controls, also analyzing the impact of the visual system on postural control. Furthermore, we investigate if the maintenance of the upright standing posture in athletes is influenced by their level of expertise and/or by their team role.

2. Materials and Methods

2.1 Subjects

Forty-six volleyball players were recruited from different Italian teams: nine of them were recruited from national professional teams (Italian championship “B2 series”) and the others from regional semi-professional teams. All of them regularly practiced volleyball. The national athletes were involved in training sessions 3-4 times per week, while the semi-professional players trained 2-3 times per week. Each training session lasted two hours. A weekly match completed the athletes’ training. The group was composed of athletes trained to play in different positions. There were 15 outside hitters, 16 central hitters, 2 opposite hitters, 9 setters, and 4 liberos. The different positions were uniformly distributed among athletes of different levels. In particular, among the nine athletes recruited from national teams there were 3 setters, 3 outside hitters and 3 central hitters. To study postural differences of athletes specialized in different roles, we chose to divide hitters (attackers) from other roles (defenders). In the “hitters” group we included outside, central, and opposite hitters, while in the “other roles” group we included setters and liberos.

The control group consisted of 42 healthy subjects recruited from the students of the University of Torino, Italy. Table 1 reports gender, age and anthropometric characteristics of both groups.

Both athletes and controls underwent orthoptic and neuro-ophthalmologic examination at Clinica Oculistica dell’Università di Torino (Torino, Italy), prior to the posturographic test, to evaluate the visual system. They were examined for visual acuity, autorefractometry and subjective refraction for the determination of the refractive error, strabismus (cover test), fusional amplitudes at far and near distances (prism bar) and ocular motility (optokinetic nystagmus, smooth pursuit and saccades). All the subjects presenting refractive errors reached a normal visual acuity with correction. The outcome of the examination is summarized in the second part of Table 1.

The local ethical committee approved the experimental protocol and all participants gave their written informed consent to be included in the study.

2.2 Acquisition protocol

To highlight the specific abilities of each subject in various conditions that stimulate the visual and vestibular systems, we applied an acquisition protocol already used in a previous work (Agostini,

Chiaramello, Bredariol, Cavallini, & Knaflitz, 2011). This protocol adds to the traditional frontal open and closed-eye conditions (Baratto, Morasso, Re, & Spada, 2002; Prieto, Myklebust, Hoffman, Lovett, & Myklebust, 1996; Raymakers, Samson, & Verhaar, 2005), conditions in which the subject is evaluated after a fast or slow head rotation, to the left or to the right side, both with eyes open and closed.

Subjects were asked to stand quietly in upright position, with arms at their sides, over a Kistler 9286A force platform. The inter-malleolar distance was fixed at 4 cm and the feet opening angle was 30°. The acquisition protocol consisted of a single trial in 10 different conditions, five with the subject's eyes open (looking at a visual target) and five with their eyes closed. The head positions were: frontal and head rotated left/right after a slow/fast head rotation. At the operator's order, the subject reached the requested head position and maintained it until the end of the acquisition. Specifically, the 10 conditions were: (1) open eyes frontal (OEF), (2) closed eyes frontal (CEF), (3) open eyes and head rotated after a slow left rotation (OELs), (4) closed eyes and head rotated after a slow left rotation (CELs), (5) open eyes and head rotated after a slow right rotation (OERs), (6) closed eyes and head rotated after a slow right rotation (CERs), (7) open eyes and head rotated after a fast left rotation (OELf), (8) closed eyes and head rotated after a fast left rotation (CELf), (9) open eyes and head rotated after a fast right rotation (OERf), (10) open eyes and head rotated after a fast right rotation (CERf).

A biaxial accelerometer fixed to the forehead of the subject allowed us to determine when the requested head position was reached. The accelerometric signal was acquired synchronously with the platform signals with the system Step32 (DemItalia, Italy). The sampling frequency was 2 kHz and the signals were then down-sampled to 20 Hz. Each recording started just before the operator's order and lasted 70 seconds. Then, an epoch of 60 s was extracted for the subsequent analysis, starting when the head position became steady, i.e. discarding the few seconds that the subject used to rotate their head after the operator's order.

The sequence of acquisitions was randomized to avoid data being biased by learning and/or fatigue effects (Tarantola, Nardone, Tacchini, & Schieppati, 1997). Every two acquisitions the subject rested one minute, moving away from the platform.

2.3 Data analysis

2.3.1 Visual skills

We applied a χ^2-test for the comparison of two proportions (independent samples) to assess the differences between visual skills of volleyball players and controls. We considered 2 × 2 contingency tables (1 degree of freedom) to evaluate group difference for: a) visual acuity, b) saccades in the range of normality and c) orthophoria (see Table 1).

2.3.2 CoP parameters

We calculated, for each condition, the major geometrical and time-domain parameters based on the CoP (Agostini, Chiaramello, Bredariol, Cavallini, & Knaflitz, 2011; Baratto, Morasso, Re, & Spada, 2002; Prieto, Myklebust, Hoffman, Lovett, & Myklebust, 1996; Raymakers, Samson, & Verhaar, 2005). The definition of the 7 CoP parameters considered is reported in Table 2.

To avoid data being biased because of anthropometric characteristics (Chiari, Rocchi, & Cappello, 2002) we normalized the parameter values with respect to the subjects' body height when the correlation between each parameter and subjects' body height was statistically significant ($p \leq 0.05$).

After normalization, we calculated for each group the mean and standard deviation of each CoP parameter/condition, and compared the two populations by means of a two-sample *t*-test. Moreover, within each group, we tested open-eye vs. closed-eye conditions, to assess the visual contribution in postural control.

2.3.3 MANOVA analysis

We obtained a total of 70 dependent variables (DVs): 10 conditions × 7 parameters. Looking at one parameter/condition at a time, it is necessary to understand which parameter/condition can differentiate the two groups (see Section 2.3.2), but it may be limiting. In fact, a variable that is

useless by itself may be useful with others (Guyon & Elisseeff, 2003). Therefore, we were interested in taking into account the inter-relations among CoP parameters in the different conditions. To this purpose we applied a multivariate analysis of variance (MANOVA) approach (Mardia, Kent, & Bibby, 1979; Krzanowski, 1988; Johnson & Wichern, 2002).

We applied a 1-factor MANOVA to compare:

a) volleyball players and controls. DVs: 10 conditions (OEF, OELs, OERs, OELf, OERf, CEF, CELs, CERs, CELf, CERf) × 7 parameters

b) volleyball players and controls, in eyes-open conditions. DVs: 5 conditions (OEF, OELs, OERs, OELf, OERf) × 7 parameters

c) volleyball players and controls, in eyes-closed conditions. DVs: 5 conditions (CEF, CELs, CERs, CELf, CERf) × 7 parameters

d) players of different expertise (national, regional) and controls. DVs: 10 conditions × 7 parameters

e) players with different team roles (hitters, other roles) and controls. DVs: 10 conditions × 7 parameters.

The MANOVA approach considered provided both a graphical representation of data (multivariate descriptive statistics) by means of canonical variate analysis (CVA), and a multivariate inferential test (Wilk's Λ) (Krzanowski, 1988). This allowed us to associate a pictorial representation of data with rigorous *p*-values. In CVA, the canonical variables C are linear combinations of the original variables, chosen to maximize the separation among groups. Specifically, the first canonical variable C_1 is the linear combination of the original variables that has the maximum separation among groups. This means that among all possible linear combinations, the first canonical variable is the one with the most significant F-statistics in a 1-way analysis of variance. The second canonical variable C_2 has the maximum separation being orthogonal to C_1, and so on.

3. Results

First we present the results of the orthoptic and neuro-ophthalmologic examination, secondly the *t*-test for each single postural parameter/condition (Fig. 1), and then the MANOVA analysis (Figs. 2-3).

3.1 Visual skills

The χ^2-test evidenced that volleyball players showed better visual acuity (p = 0.02) and more normal saccades (p = 0.01) than controls. The orthophoria was not different between the groups.

3.2 CoP parameters

Figure 1 shows the mean and standard deviation of each parameter for athletes and controls in the 10 conditions. Statistically significant differences between groups are indicated with an asterisk ($p \leq 0.05$). The Mean Velocity was not significantly different between groups, but volleyball athletes always showed higher values than controls. The Sway Area differentiated the two groups only in a few test conditions. The Major and Minor Axis, RMS AP and RMS ML showed significant differences in the majority of the conditions. The Eccentricity did not differentiate the two groups. Furthermore, considering each group separately, we compared open eyes vs. closed eyes performances. The Mean Velocity showed significant differences in all test conditions, for both groups. For the other parameters, statistically significant differences between eyes open and eyes closed tests were observed only in a few test conditions.

3.3 MANOVA analysis

Figure 2 shows multivariate data from athletes and controls plotted against the first two canonical variables C_1 and C_2. Fig. 2(a) reports the comparison of athletes and controls based on the complete set of 10 conditions (5 with eyes open and 5 with eyes closed). In order to evaluate the effect of the visual system, Figs. 2(b) and 2(c) consider the eyes open and eyes closed acquisitions separately. In these plots (Fig. 2(a)-(c)), the two groups are slightly separated in the canonical variables plane. They were not significantly different according to Wilk's Λ MANOVA test (p=0.26) when all the 10 conditions were considered together (Fig. 2(a)). On the contrary, the two groups were found to

be significantly different in the open-eyes conditions (p = 0.05) (Fig. 2(b)), while visual deprivation did not allow to differentiate the two groups (p = 0.20)(Fig. 3(c)).

In Fig. 3 we have considered separately athletes coming from national and regional teams and playing different team roles. Figure 3(a) reports multivariate data relative to athletes at a national level, athletes at a regional level, and controls. The three groups are well separated in the canonical variables plane (Wilk's Λ test: p = 0.001). More specifically, volleyball players recruited from national teams are far apart from the other two groups, while the regional group is only slightly apart from controls. Note that the "national" group is separated from the "regional" and "control" group along the first canonical variable C_1, while it is only the second canonical variable C_2 that separates the "regional" group from controls.

Fig. 3(b) reports multivariate data relative to volleyball athletes playing as "hitters", playing as "other roles", and non-athlete controls. The three groups are separated in the canonical variables plane and the MANOVA test was very close to being statistically significant (p = 0.058). Note that the group constituted by setters and liberos is the one that is the most distant from the other two groups.

4. Discussion

In literature there are few studies examining balance performances in volleyball players. Most of these studies focus on the effect of proprioceptive balance training in reducing the risk of ankle sprains among volleyball athletes (Verhagen et al., 2004; McGuine & Keene, 2006), but they do not assess balance performances with quantitative tests. Only one study (Kuczyński, Rektor, & Borzucka, 2010) is directly comparable to ours, at least in some aspects.

Our work analyzes the visual skills of athletes and non-athletes, in order to better understand the postural differences between the groups and then delves deeper into these differences taking into account the level and the playing position of the athletes.

4.1 Influence of visual skills on balance performances

It is well known that visual skills play an important role in open eyes balance control (Winter, 1995), while closed eyes standing does not depend on vision.

Results of the orthoptic examination show that refractive errors are more numerous in controls than in athletes, but during the balance test all the subjects had refractive correction and reached normal visual acuity. Hence, from a (static) visual acuity point of view, volleyball players cannot be considered different from controls.

However, when a moving target is considered, 'dynamic' visual acuity of athletes is definitely superior to that of controls (see e.g. Ishigaki& Miyao, 1993).

It was demonstrated that female volleyball athletes show better facility of accommodation and saccadic eye movements (SEM) than the non-playing control group (Jafarzadehpur, Aazami, & Bolouri, 2007). Similarly, in our population volleyball players showed adequate SEM in 78.3% of cases, while this was found in only 52.4% of controls. Moreover, it was reported that in a game situation, expert volleyball players adopt a different gazing strategy than non-expert players (Piras, Lobietti, & Squatrito, 2010).

Using a multivariate approach we found that the 5 open-eye conditions allow to distinguish athletes from controls ($p = 0.05$), while, considering closed-eye conditions, the difference between groups is not statistically significant ($p = 0.20$). This shows that "ocular training" of volleyball players has an influence not only in a game situation, as already demonstrated (Piras, Lobietti, & Squatrito, 2010), but also in static balance control. Emery (2003) indicated measures of dynamic standing as the proper tool in investigating athlete postural control. Our findings suggest that also stabilometric tests in bipedal static conditions could be a useful tool in the evaluation of postural performances of volleyball athletes.

4.1 Differences between volleyball players and controls

Kuczyński et al. (2010) analyze the balance performances of 23 volleyball players recruited from the Polish male second league. This study reports that players have lower CoP variability in the ML direction and lower CoP range than controls in both AP and ML directions. The CoP mean velocity

of athletes was higher than that of controls. Our results are in partial agreement with Kuczyński's study. In fact, we found that the mean velocity of the CoP resultant in OEF shows greater values for volleyball players than for controls, but in our study this difference is not statistically significant ($p = 0.19$). Differently from Kuczyński et al. (2010), we found that RMS AP and RMS ML have greater values in athletes than in controls, although these differences are not always statistically significant.

These discrepancies between our study and Kuczyński's work may be explained by different factors: a) the authors of the cited study considered only male athletes, while we considered both females and males, b) they considered only 1 condition (eyes open frontal), while we considered 10 conditions (5 with eyes open and 5 with eyes closed) following the indications suggested by Ruhe et al. (2010), c) their test lasted only 20 s, while our test lasted 60 s (which should guarantee a better reliability of the results, as suggested by Doyle et al. (2007) and by Ruhe et al. (2010)). Moreover, Kuczyński did not apply the standardization of CoP parameters with respect to the anthropometric characteristics and this can bias the data (Chiari, Rocchi, & Cappello, 2002; Ruhe, Fejer, & Walker, 2010).

In the literature, a greater CoP trajectory is usually interpreted as lower stability (e.g. Prieto, Myklebust, Hoffman, Lovett, & Myklebust, 1996). Nevertheless, there are various studies demonstrating a greater sway ellipse of athletes with respect to non-athletes, which may be read as a paradox. As an example, a study on young male athletes practicing canoeing and kayaking reports larger CoP mean amplitudes and sway velocity for the athletes (Strambolieva, Diafas, Bachev, Christova & Gatev, 2012). Another study reports that synchronized ice skaters unexpectedly showed less 'balance' than controls in upright stance on a rigid force platform (Alpini, Mattei, Schlecht & Rohen-Raz, 2008). We believe that caution is needed in the interpretation of larger sway ellipses as indicators of a poorer balance of athletes with respect to non-athletes. Similarly to what was found in the cited studies, our work demonstrated that volleyball players show greater values of RMS AP, RMS ML, Major and Minor Axis with respect to controls. We hypothesize that this is due

to the attitude that these athletes develop in order to quickly react to each game situation moving rapidly from a static position. This is consistent with the hypothesis of a different model of sensory integration in the postural stability of athletes (Strambolieva, Diafas, Bachev, Christova & Gatev, 2012).

4.2 Different athlete expertise and team roles

Considering the information arising from the 10-condition protocol, we demonstrated that it is possible to separate volleyball players of national level from athletes of regional level and controls. The data presented suggest that the level of expertise of the players influences their postural control in static conditions: the higher the training level, the more remarkable the difference between athlete and non-athlete performances. Jafarzadehpur et al. (2007) investigated the visual skills of volleyball players with different levels of expertise: beginner, intermediate, and advanced players. They observed better visual performance in advanced players than in the others. This can be an indirect confirmation of our findings, since the visual system and sensory-motor coordination are mutually interrelated.

In an analogous way, we observed that athletes trained in different team roles (hitters, setters and liberos) have different balance performances. Hitters are usually trained to respond to a single playing scheme and may have longer reaction times than defenders. In fact, they have to react quickly only if the ball is received in the wrong way. Their specific skill is elevation. They express their coordination and balance abilities especially when they jump in the air to make contact with the ball. On the contrary, setters rapidly move toward the moving ball and quickly decide which scheme is better to apply, choosing to which attacker they should deliver the ball. Setters must always have very short reaction times. Liberos are exclusively defensive players. They are usually the players on the court with the quickest reaction time and best passing skills. In literature, anthropometric differences are described among hitters, setters and liberos (Marques, van de Tillaar, Gabbett, Reis, & Gozalez-Badillo, 2009). However, since we normalized our data with respect to height, these differences should not significantly influence our findings. We hypothesize

that the postural differences observed among different team roles are due to the specific training undergone by these athletes rather than to their body structure.

5. Conclusion

In this study we investigated the postural control of volleyball players in bipedal static conditions. We demonstrated that athletes differ from non-athletes in the open-eyes conditions. More specifically, the sway ellipse and other CoP parameters were larger for athletes. This might be erroneously interpreted as volleyball showing worse balance performances. We hypothesized that this result could be explained as an adaptation of athletes to a postural scheme that integrates the visual system differently with respect to untrained subjects.

Furthermore, we demonstrated that national level athletes differed from regional level ones in upright stance. This difference may be due to the different intensity levels of their training and/or to the subjective aptitude of the athletes.

We also observed a different postural stability of defensive players with respect to hitters. We hypothesized that this difference is mainly due to their quicker reaction times.

The protocol presented in this work might be useful to assess the efficacy of intensive sport training programs involving the integration of proprioceptive and visual systems and/or to select elite players with an aptitude for a specific playing role.

References

Alpini, D., Mattei, V. Schlecht, H., Kohen-Raz, R., Postural control modifications induced by synchronized ice skating (2008). *Sport Sci Health, 2,* 11–17.

Agostini, V., Chiaramello, E., Bredariol, C., Cavallini, C., & Knaflitz, M. (2011). Postural control after traumatic brain injury in patients with neuro-ophthalmic deficits. *Gait Posture, 34,* 248–253.

Arkov, V. V., Abramova, T. F., Nikitina, T. M., Ivanov, V. V., Suprun, D. V., Shkurnikov, M. U., & Tonevitskii, A. G. (2009). Comparative study of stabilometric parameters in sportsmen of various disciplines. *Bull Exp Biol Med, 147* (2), 233–235.

Baratto, L., Morasso, P. G., Re, C., & Spada, G. (2002). A new look at posturographic analysis in the clinical context: sway-density vs. other parameterization techniques. *Motor Control, 6,* 246–270.

Bieć, E., & Kuczyński, M. (2010). Postural control in 13-year-old soccer players. *Eur J Appl Physiol, 110,* 703–708.

Chiari, L., Rocchi, L., & Cappello, A. (2002). Stabilometric parameters are affected by anthropometry and foot placement. *Clinical Biomechanics, 17,* 666–677.

Dai, B., Sorensen, C. J., & Gillette, J. C. (2010). The effects of postseason break on stabilometric performance in female volleyball players. *Sports Biomechanics, 9* (2), 115–122.

Doyle R. J., Hsiao-Wecksler, E.T., Ragan, B. G., Rosengren, K. S. (2007). Generalizability of center of pressure measures of quiet standing. *Gait Posture, 25,* 166–171.

Emery, C. A. (2003). Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. *J Sci Med Sport, 6* (4), 492–504.

Gerbino, P. G., Griffin, E. D., & Zurakowski, D. (2007). Comparison of standing balance between female collegiate dancers and soccer players. *Gait Posture, 26,* 501–507.

Golomer, E., Cremieux, J., Dupui, P., Isableu, B., & Ohlmann, T. (1999) Visual contribution to self-induced body sway frequencies and visual perception of male professional dancers. *Neurosci Lett, 267,* 189–192.

Guyon, I., & Elisseeff, A. (2003). An Introduction to Variable and Feature Selection. *Journal of Machine Learning Research, 3,* 1157–1182.

Ishigaki, H., & Miyao, M. (1993). Differences in dynamic visual acuity between athletes and nonathletes. *Percept Mot Skills, 77,* 835–839.

Jafarzadehpur, E., Aazami, N., & Bolouri, B. (2007). Comparison of saccadic eye movements and facility of ocular accommodation in female volleyball players and non-players. *Scand J Med Sci Sports, 17,* 186–190.

Johnson, R., & Wichern, D. (2002). *Applied multivariate statistical analysis*. (5th ed.). New Jersey: Prentice Hall.

Krzanowski, W. J., (1988). *Principles of multivariate analysis: A user's perspective*. Oxford, UK: Clarendon Press.

Kuczyński, M., Rektor, Z., & Borzucka, D. (2009). Postural control in quiet stance in the second league male volleyball players. *Human movement, 10* (1), 12–15.

Mardia, K. V., Kent, J. T., & Bibby, J. M. (1979). *Multivariate Analysis*. London, UK: Academic Press.

Marques, M. C., van de Tillaar, R., Gabbett, T. J., Reis, V. M., & Gozalez-Badillo, J. J. (2009). Physical fitness qualities of professional volleyball players: determination of positional differences. *Journal of Strength and Conditioning Research, 23* (4), 1106–1111.

McGuine, T. A., & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *Am J Sports Med, 34* (7), 1103–1111.

Paillard, T., & Noé, F. (2006). Effect of expertise and visual contribution on postural control in soccer. *Scand J Med Sci Sports, 16,* 345–348.

Perrin, P., Deviterne, D., Hugel, F., & Perrot, C. (2002). Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait Posture, 15,* 187–194.

Petersen, W., Braun, C., Bock, W., Schmidt, K., Weimann, A., Drescher, W., Eiling, E., Stange, R., Fuchs, T., Hedderich, J., & Zantop, T. (2005). A controlled prospective case control study of a

prevention training program in female team handball players: the German experience. *Arch Orthop Trauma Surg, 125,* 614–621.

Piras, A., Lobietti, R., & Squatrito, S. (2010). A study of saccadic eye movement dynamics in volleyball: comparison between athletes and non-athletes. *J Sports Med Phys Fitness, 50,* 99–108.

Prieto, T., Myklebust, J. B., Hoffman, R. G., Lovett, E. G., & Myklebust, B. M. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng, 43* (9), 956–966.

Raymakers, J. A., Samson, M. M., & Verhaar, H. J. J. (2005). The assessment of body sway and the choice of the stability parameter(s). *Gait Posture, 21,* 48–58.

Rougier, P., & Garin, M. (2007). Performing saccadic eye movements or blinking improves postural control, *Motor Control, 11,* 213–222.

Ruhe, A., Fejer, R., & Walker, B. (2010). The test-retest reliability of the centre of pressure measures in bipedal static task conditions- A systematic review of the literature. *Gait Posture, 32,* 436–445.

Schmit, J. M., Regis, D. I., & Riley, M. A. (2005). Dynamic patterns of postural sway in ballet dancers and track athletes. *Exp Brain Res, 163,* 370–378.

Söderman, K., Werner, S., Pietilä, T., Engström, B., & Alfredson, H. (2000). Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surg Sports Traumatol Arthrosc, 8,* 356–363.

Strambolieva, K., Diafas, V., Bachev, V., Christova, L., & Gatev, P. (2012). Postural stability of canoeing and kayaking young male athletes during quiet stance. *Eur J Appl Physiol, 112,* 1807–1815.

Tarantola, J., Nardone, A., Tacchini, E., & Schieppati, M. (1997). Human stance stability improves with the repetition of the task: effect of foot position and visual condition. *Neurosci Lett, 228,* 75–78.

Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R., & van Mechelen, W. (2004).The effect of a proprioceptive balance board training program for the prevention of ankle sprains. A prospective controlled trial. *Am J Sports Med, 32* (6), 1385–1392.

Vuillerme, N., Danion, F., Marin, L., Boyadjian, A., Prieur, J. M., Weise, I., & Nougier, V. (2001). The effect of expertise in gymnastics on postural control. *Neurosci Lett, 303,* 83–86.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait Posture, 3,* 193–214.

Table 1. Description of the two populations

Anthropometric characteristics		Volleyball players (N = 46)		Controls (N = 42)	
Gender		26 males	20 females	16 males	26 females
Age (years)	mean±std	25.9±6.2	22.9±2.9	25.2±5.4	22.4±2.8
	range	19–37	19–29	19-39	18-28
Height (cm)	mean±std	185.6±7.7	170.8±7.9	179.1±6.9	166.9±5.3
	range	163–200	155–184	169-196	155-175
Weight (kg)	mean±std	79.2±8.1	62.4±8.5	75.1±9.1	57.4±6.9
	range	59–93	46–75	55-94	44-72

Orthoptic and neuro-ophthalmologic examination	Volleyball players (N = 46)	Controls (N = 42)
No visual correction	57.1%	30.9%
Visual correction:		
myopia	36.9%	54.7%
hypermetropia	4.3%	7.1%
astigmatism	4.3%	11.9%
Orthophoria	39.1%	33.3%
Saccades in the range of normality	78.3%	52.4%

Figure legends

Figure 1 – Comparison of posturographic parameters between volleyball athletes and controls: mean values and standard deviation are shown for each parameter and each condition is listed in the legend.

* Significant difference between athletes and controls ($p < 0.05$)

△ Significant difference between eyes open and closed, in controls ($p < 0.05$)

○ Significant difference between eyes open and closed, in volleyball athletes ($p < 0.05$)

Figure 2 – Athletes and controls: scatter plots of the first (C_1) vs. the second (C_2) canonical variable. (a) All 10 conditions. (b) Open-eye conditions (OEF, OELs, OERs, OELf, OERf). (c) Closed-eye conditions (CEF, CELs, CERs, CELf, CERf).

Figure 3 – Athletes and controls: scatter plots of the first (C_1) vs. the second (C_2) canonical variable. Different (a) training expertise, and (b) team roles are considered (all 10 conditions).

Figure 1

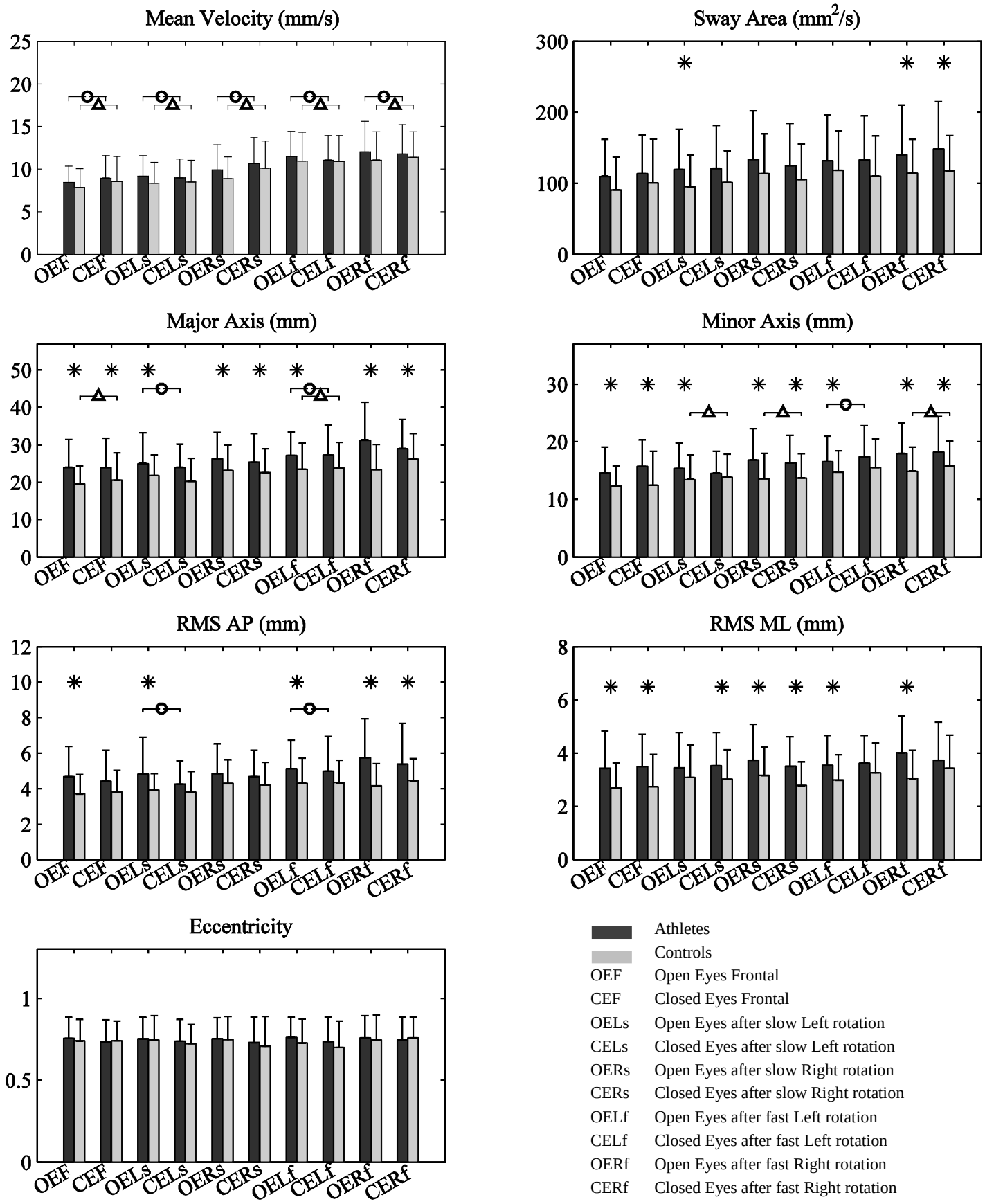

Mean Velocity (mm/s)
Sway Area (mm2/s)
Major Axis (mm)
Minor Axis (mm)
RMS AP (mm)
RMS ML (mm)
Eccentricity
OEF
CEF
OELs
CELs
OERs
CERs
OELf
CELf
OERf
CERf
Athletes
Controls
OEF Open Eyes Frontal
CEF Closed Eyes Frontal
OELs Open Eyes after slow Left rotation
CELs Closed Eyes after slow Left rotation
OERs Open Eyes after slow Right rotation
CERs Closed Eyes after slow Right rotation
OELf Open Eyes after fast Left rotation
CELf Closed Eyes after fast Left rotation
OERf Open Eyes after fast Right rotation
CERf Closed Eyes after fast Right rotation

Figure 2

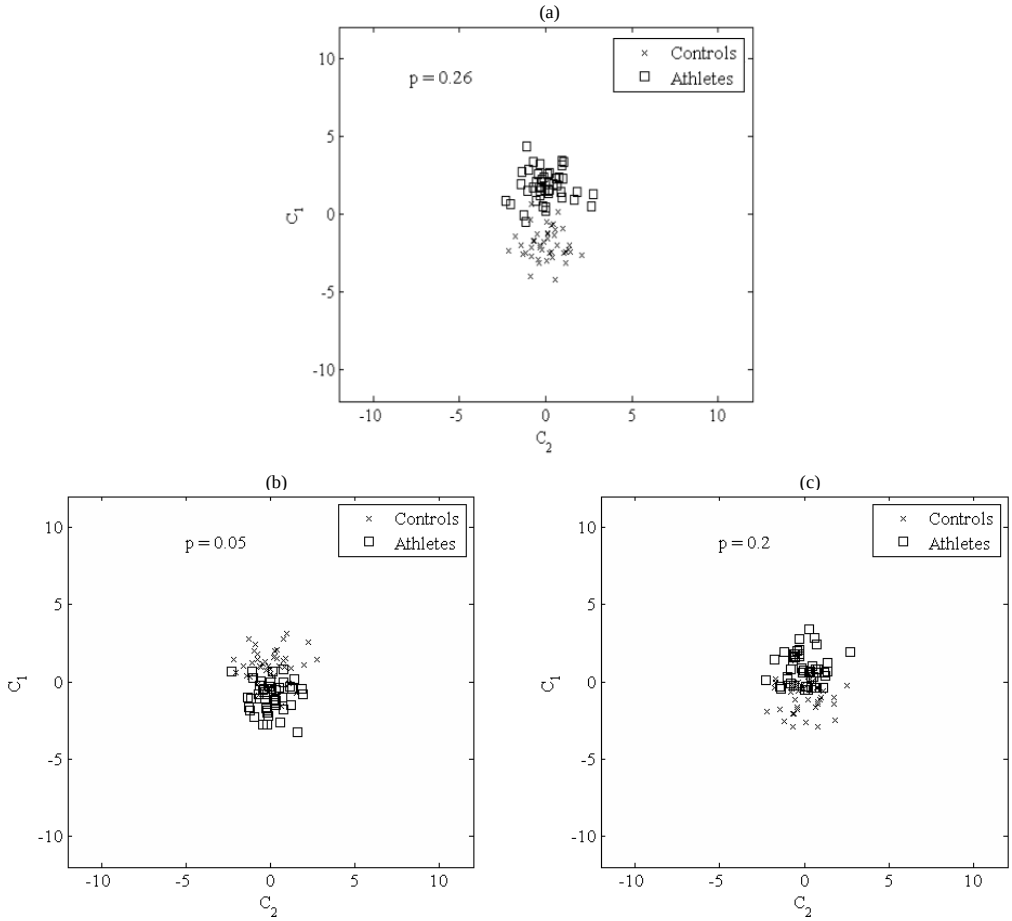
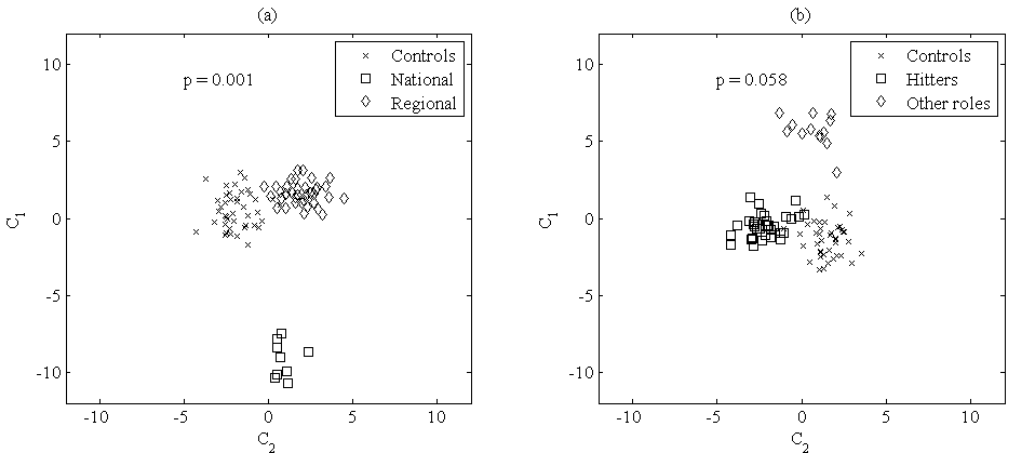

(a)
p = 0.26
Controls
Athletes
C1
C2
(b)
p = 0.05
Controls
Athletes
C1
C2
(c)
p = 0.2
Controls
Athletes
C1
C2

Figure 3


(a)
p = 0.001
Controls
National
Regional
C1
C2
(b)
p = 0.058
Controls
Hitters
Other roles
C1
C2