Gait & Posture 90 (2021) 48–54

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Static balance performance differs depending on the test, age and specific role played in acrobatic gymnastics

Luis Arturo Gómez-Landero [a,*], Pureza Leal del Ojo [b], Cherie Walker [c], Pablo Floría [a]

[a] Physical Performance & Sports Research Center, Universidad Pablo de Olavide, Ctra. de Utrera, km. 1, 41013, Seville, Spain
[b] San Isidoro University Center, Cartuja Island, Seville, Spain
[c] The New South Wales Institute of Sport, Sydney Olympic Park, Australia

ARTICLE INFO

Keywords:
Single-leg balance
Headstand balance
Age
Players' position
Gymnastics

ABSTRACT

Background: Static balance performance appears to detect differences between roles played in team sports. Static balance can also be influenced by the subject's height and age, and the type of test used.
Research question: Could the static balance profile show differences among the role played depending on the specific test evaluated and the gymnasts' age?
Methods: A cross-sectional design was applied. 46 acrobatic gymnasts (37 females and 9 males) were divided in four groups according to role (base or top gymnast) and stage of adolescence (early adolescent or mid-adolescent) during two different static tests: (1) unipedal with open and closed eyes (generic), and (2) headstand (specific). To test the effect of the role and the age group, a two-way analysis of variance (ANOVA) between groups was performed. Centre of pressure (COP) measurements were obtained and normalised relative to participants height, including length travelled on the anteroposterior and mediolateral axis (AP_CoP and ML_CoP) and the mean speed (SP_CoP).
Results: Base gymnasts obtained lower values in the CoP excursion than Top gymnasts but only in unipedal tests for all the variables analysed ($5.536 \geq F_{1,42} \leq 10.589$, $0.002 \geq p \leq 0.023$), except for the AP_CoP in unipedal-closed. Mid-adolescent gymnasts obtained lower values in the CoP excursion regardless of the task than early adolescent ($5.324 \geq F_{1,42} \leq 14.805$, $0.000 \geq p \leq 0.026$).
Significance: It has been observed a clear effect of age on the static balance manifested in acrobatic gymnastics, regardless of the subject's height, the role played, and the test performed. The effect of the role played in this team sport has been different depending on the type of test performed.

1. Introduction

The acute control of posture can be associated with the sports performance [1]. There is evidence that athletes at all ages, regardless of the practiced sport, generally showed higher postural stability when compared with non-athletes [2]. Differences in balance ability have also been observed between sports. These differences may be due to the specific demands and type of balance required of each sport [3].

The balance test has been shown to be sensitive enough to detect subtle differences between athletes with different roles in team sports, like a handball [4] or soccer [5]. However, studies analysing the difference between different roles in the sports team are limited, with the reported results not being clear due to the possible influence of the different heights of the players [6]. To avoid data being biased because of anthropometric characteristics, Agostini et al. [7] normalised the data with respect to height when analysing postural sway of volleyball players with different role. Additional research that control height are necessary to know the effect of the role on balance, especially when evaluating subjects with disparate heights [1,3]

Age could be another factor considered to analyse the postural control. During natural bipedal stance with the eyes open, many studies in healthy children reported a decrease in postural sway with increasing age, with conflicting results on the (non-)linearity of its development [8]. The review study noted that it remains unclear between which age groups differences are found [8], although there is evidence of an improvement in the maintenance of static positions with maturation. In

* Corresponding author.
E-mail addresses: lagomrod@upo.es (L.A. Gómez-Landero), pdelojo@centrosanisidoro.es (P. Leal del Ojo), cwal05@gmail.com (C. Walker), pfloriam@upo.es (P. Floría).

https://doi.org/10.1016/j.gaitpost.2021.07.023
Received 29 April 2021; Received in revised form 8 July 2021; Accepted 28 July 2021
Available online 31 July 2021

Table 1
Physical characteristics of the participants (mean values ± SD).

	Early adolescent		Mid-adolescent	
	Base (n = 6)	Top (n = 18)	Base (n = 17)	Top (n = 5)
Height (cm)	148.22±7.56	137.56±6.89	161.36±9.98	155.08±6.57
Weight (kg)	40.25±6.57	31.13±4.58	57.27±12.45	43.77±3.87
Age (years)	11.83±0.41	10.89±0.83	15.65±1.5	13.8±0.84

other balance tests, specific to gymnastic sports, older gymnasts also showed a better ability to control body position in the handstand [9,10].

The static balance performance may also differ depending on the type of test used for its evaluation. The ability to maintain a static balance during sport specific tasks appears to be unrelated to the results manifested on non-specific tasks [1,11]. The sport specific balance task seems to be more selective in representing the athlete's level [12,13]. Therefore, the specificity of the test could differentiate the balance capacity according to the role played within the team, however there is a lack of knowledge on this issue.

The ability to hold very different static positions, both inverted and standing, is especially characteristic in Acrobatic Gymnastics [14,15]. In this team sport, gymnasts perform individual static postures (held for two seconds) and compulsory static group positions (called pyramids, held for three seconds) with the top partner in different positions above the other gymnast. Two roles are distinguished during the formation of pyramids; one gymnast on the base (base gymnast) while supporting their partner on the top (top gymnast) [14]. Some studies have analysed static balance during the execution of pyramids [15,16], but the effect of the role played on individual balance is still unknown.

Following research reviewed, doubts arise about the effect of the role played on the static balance performance. An investigation considering sport-specific tasks, the age, and the height of the subjects, would allow progress in knowledge about the effect of the role on balance performance.

The purpose of the current study was to examine the effect of role played and age with different static tests in young acrobatic gymnasts. We hypothesized that (1) the static balance profile would show significant differences among the role of acrobatic gymnast depending on the balance test conducted, (2) the more aged gymnasts would display better static balance both in standing and inverted postures.

2. Methods

2.1. Participants

Forty-six acrobatic gymnasts (consisting of 37 females and 9 males) were recruited. All participants were in the 10–18 age category (junior category in the Royal Spanish Gymnastics Federation regulations) and had a minimum of two years of experience in national competitions. Participants were divided into four groups according to role (base or top gymnast) and stage of adolescence (early adolescent, 10–13 years; mid-adolescent, >13-18 years): Early Base (n = 6), Early Top (n = 18), Mid-Base (n = 17), Mid-Top (n = 5). The characteristics of the participants are described in Table 1. All participants were free from any musculoskeletal injury that may have interfered with their ability to perform the selected balance tasks. The study had ethical approval from the local University Research Ethics Committee. All adult participants and parents/guardians of children participants signed informed consent forms before participating in the study.

2.2. Testing protocol

Each gymnast was instructed to perform two different static postures on the regular surface of a single force platform (AMTI AccuPower, Watertown, MA, USA). An inverted position (specific test) and non-inverted position (generic test). The generic test selected was unipedal stance on the preferred leg (Fig. 1 -A-), and was performed under two visual conditions, open and closed eyes (unipedal-open, unipedal-closed), maintained for 30 s; during the unipedal-open test subjects were instructed to direct their focus forward at a fixed point. The specific test was a headstand held for 7 s. It is a specific posture in Acrobatic Gymnastics both in base and top gymnasts; gymnast executes an inverted position supported exclusively by the hands and the head with bent elbows, while the gymnast tries to keep the body in full extension (Fig. 1 -B-). An assistant was monitoring the execution, but no assistance was needed in any case.

Before data collection, the participants carried out their usual general warm-up, as well as the specific warm up for the execution of the headstand. Since all subjects regularly performed these kinds of postures in their daily training, only a brief five-minute practice was needed to ensure the participants could complete the tasks comfortably and

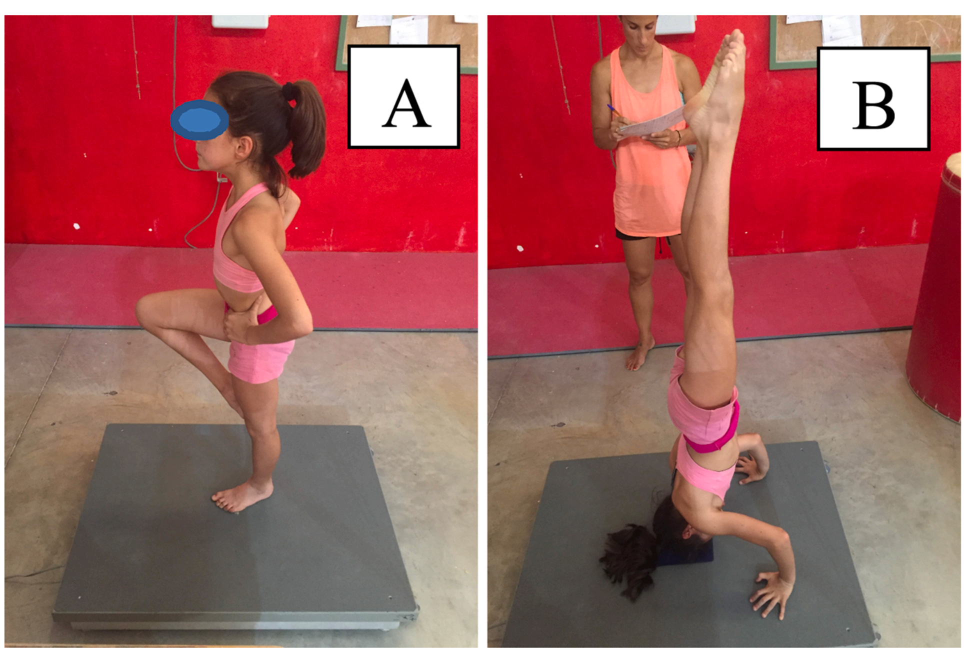

Fig. 1. Images of the balance test: unipedal (A), headstand (B).

Initial measures	Correlation coefficients in each principal component obtained: Unip.Open	Unip.Closed	Headstand
FxRange	.911	.825	.925
FxSD	.903	.848	.925
FyRange	.936	.905	.919
FySD	.901	.931	.928
CoPxRange	.741	.890	.937
CoPxRangeSD	.833	.912	.946
CoPyRange	.914	.929	.958
CoPyRangeSD	.871	.949	.956
CoPxLength	.952	.961	.948
CoPyLength	.944	.951	.959
CoPxVelSD	.952	.928	.967
CoPyVelSD	.945	.939	.965
CoPSpeedMean	.961	.966	.978
CoPSpeedSD	.904	.913	.948
% Variance explained	82.20%	84.34%	89.73%

Measures finally selected
CoPxLength
CoPyLength
CoPSpeedMean

Fig. 2. CoP parameters selected by principal components analysis with the variable-factor correlation coefficients among the 3 balance tests.

without risk in a satisfactory level before executing the static postures on the force platform.

The current study chose to use the centre of pressure (CoP) excursion as it is one of the most utilised biomechanical variables to assess postural control [17]. Three trials for each static posture were registered for each participant, at a sample frequency of 200 Hz, with at least 2 min rest allowed between attempts. The trials were presented in random order.

2.3. Data analysis

Given the differences in the height of both groups, all CoP measurements were normalised relative to participants' height. Normalising balance scores relative to body height is recommended when comparing groups with notable stature differences [18].

Choosing the appropriate measures in the CoP excursion analysis for the specific requirements of each study is often a problem [19], thus 14 CoP and horizontal force measures were initially obtained, both in the mediolateral (ml) and anteroposterior (ap) axis: range of force applied in

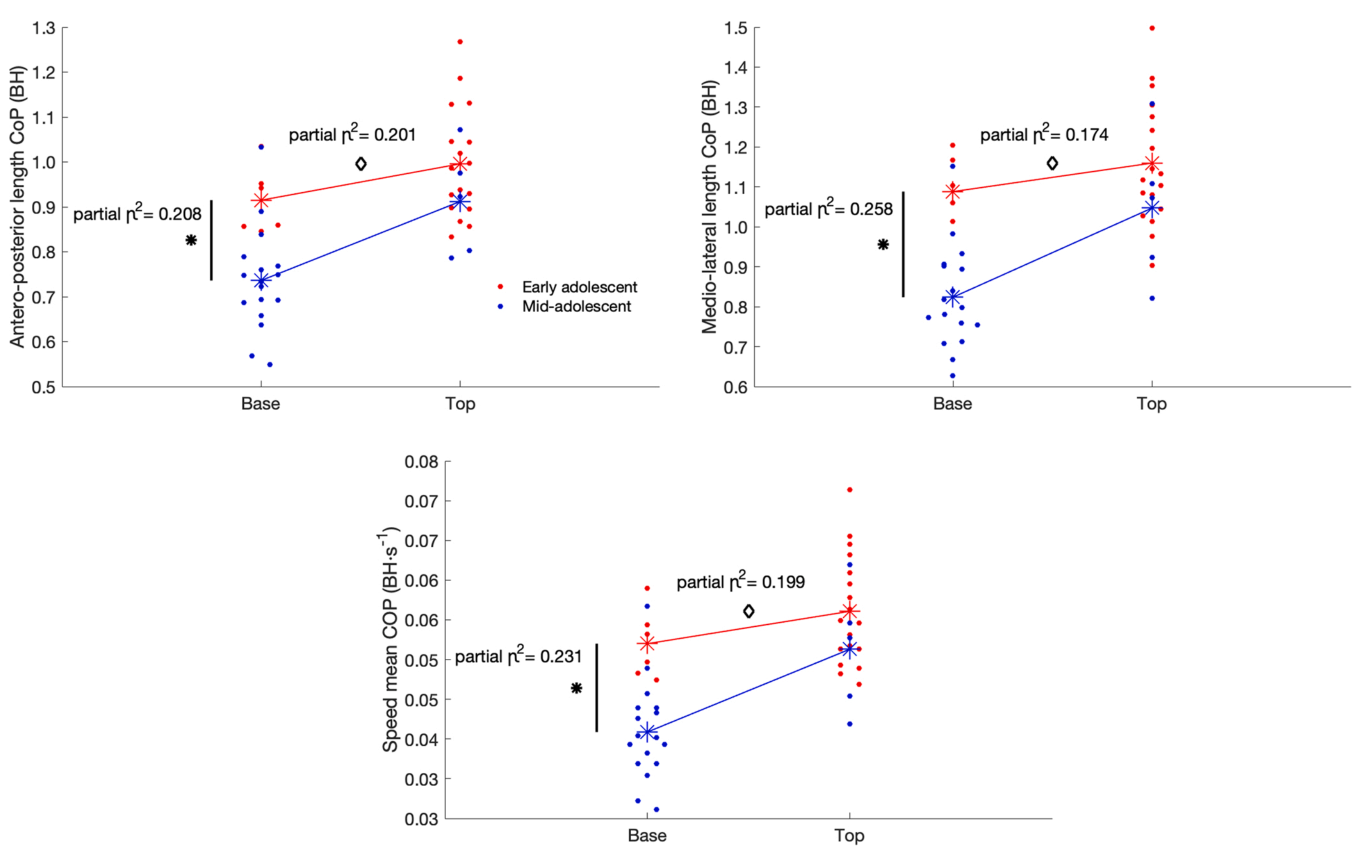

Fig. 3. Unipedal-open eyes test. Individual values and mean of centre of pressure antero-posterior length (top-left), medio-lateral length (top-right), speed mean (bottom), obtained for the 2 roles (Base and Top gymnasts), and the 2 age groups (early and mid-adolescent). CoP measurements normalised relative to body height (BH). * = $p < 0.05$ between age groups; ◊ = $p < 0.05$ between roles.

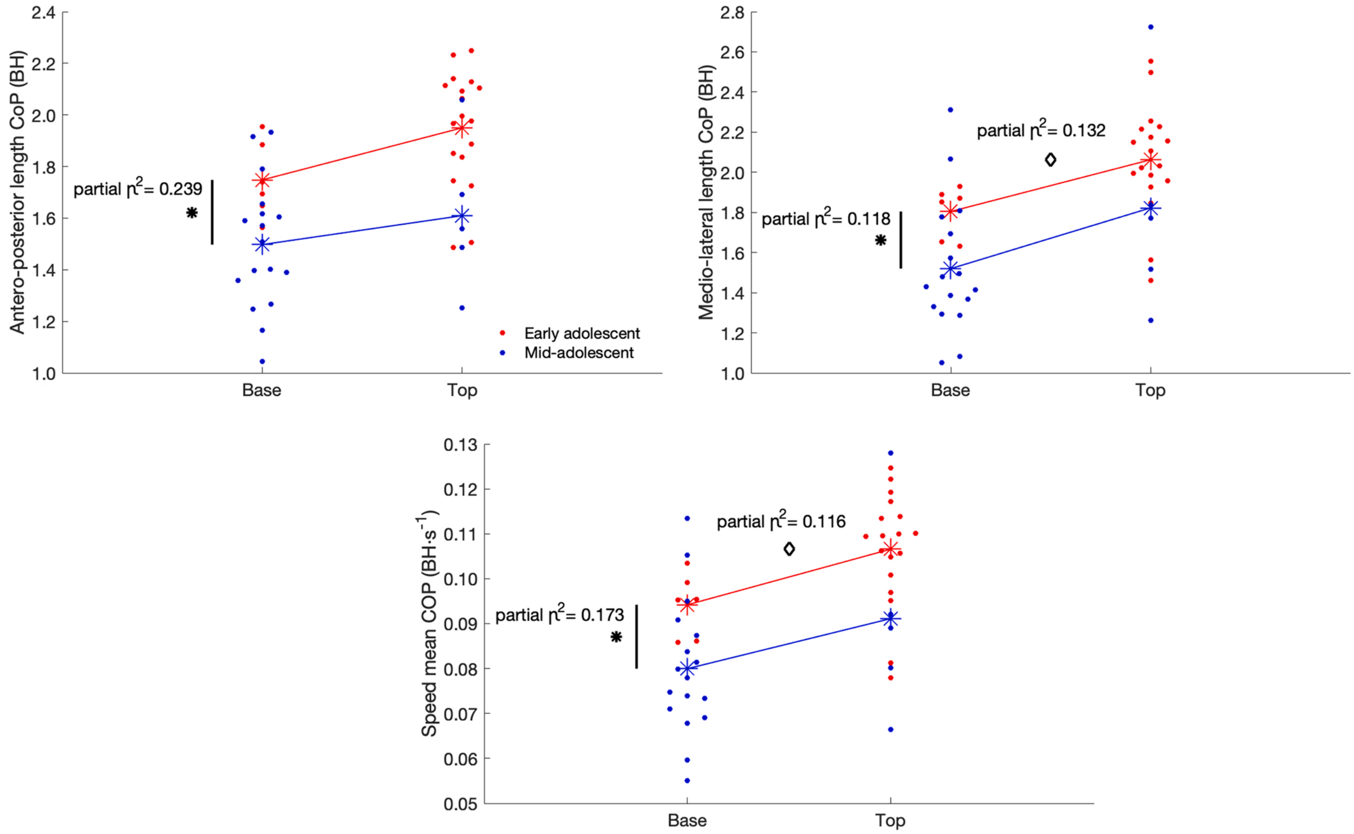

Fig. 4. Unipedal-closed eyes test. Individual values and mean of centre of pressure antero-posterior length (top-left), medio-lateral length (top-right), speed mean (bottom), obtained for the 2 roles (Base and Top gymnasts), and the 2 age groups (early and mid-adolescent). CoP measurements normalised relative to body height (BH). * = $p < 0.05$ between age groups; ◊ = $p < 0.05$ between roles.

the ap-axis (FapRange), standard deviation of applied force in ap-axis (FapSD), FmlRange, FmlSD, range of CoP location in ap-axis (CoPapRange), CoPapSD, total distance of CoP moves in the ap-axis (CoPapLength), CoPapRange, CoPmlSD, CoPmlLength, standard deviation of CoP velocity in ap-axis (CoPapVelSD), CoPmlVelSD, CoPSpeedMean, CoPSpeedSD. Finally, after a principal component analysis, 3 variables were selected: the total length travelled by the CoP on the anteroposterior and mediolateral axis (AP_CoP and ML_CoP) and the mean speed of the CoP (SP_CoP), defined as the total length of the CoP displacement divided by the duration of the trial. These CoP measures are among the most widely used and recommended [20].

2.4. Statistical analyses

Statistical analyses were conducted using SPSS version 22.0 (IBM, Armonk, NY, USA). To simplify the analysis and select the most relevant measures, a principal component analysis, correlation analysis and theoretical assessment were performed [19]. All successful trials under three conditions, unipedal open eyes (UOE), unipedal closed eyes (UCE) and headstand were included to analyse. After this process, all the initial measures were reduced to three. To verify the PCA conditions of application the Kaiser-Meyer-Olkin test (KMO), anti-image matrix of correlation coefficients, and Bartlett sphericity test were analysed. A principal component was identified with an eigen-value greater than 1 for each balance test.

To test the effect of the role (base and top) and the effect of the age group (early and mid-adolescent), for all balance test (headstand, unipedal-open, unipedal-closed), a two-way analysis of variance (ANOVA) between groups was performed (2 roles x 2 age groups). Shapiro-Wilk and Levene's tests were performed to check the normal distribution and the homogeneity of variance, respectively. Eta–squared (η^2) was calculated for effect size [21], and was interpreted as small (≈ 0.02), medium (≈ 0.25), and large (≈ 0.35). The significant alpha value was set at 0.05 for all statistics. All graphs were performed with the software MATLAB.

3. Results

In the principal component analysis, KMO test showed sample adequacy with values ≥ 0.822. All variables showed values ≥ 0.6 in the diagonal anti-image matrix, without problems of multicollinearity. The null hypothesis in the Bartlett sphericity test was also rejected ($p < 0.01$). Each principal component was identified with more than 80 % of total variance explained in all the cases. The measures with the highest average variable-factor correlation coefficients among the 3 balance tests were the length of the CoP in x (anteroposterior) and y (mediolateral), and the mean CoP speed mean (Fig. 2).

The effects of role and age on the CoP excursion in the generic (unipedal-open, unipedal-closed) and specific test (headstand) are presented in Figs. 3–5 respectively.

The effect of age on static balance was significant in generic and specific tests and for all measured variables ($5.324 \geq F_{1,42} \leq 14.805$, $0.000 \geq p \leq 0.026$). Mid-adolescent gymnasts obtained lower values in the CoP excursion. The highest effect sizes were medium-large (headstand partial $\eta^2 = .261$; unipedal-open $\eta^2 = .258$; unipedal-closed partial $\eta^2 = .239$).

By contrast, the role effect on the CoP excursion was only significant in generic tests for all the variables analysed ($5.536 \geq F_{1,42} \leq 10.589$, $0.002 \geq p \leq 0.023$), except for the AP_CoP in unipedal-closed. Base gymnasts obtained lower values in the CoP excursion. The highest effect sizes were medium (unipedal-open partial $\eta^2 = .201$, observed power = .889; unipedal-closed partial $\eta^2 = .132$).

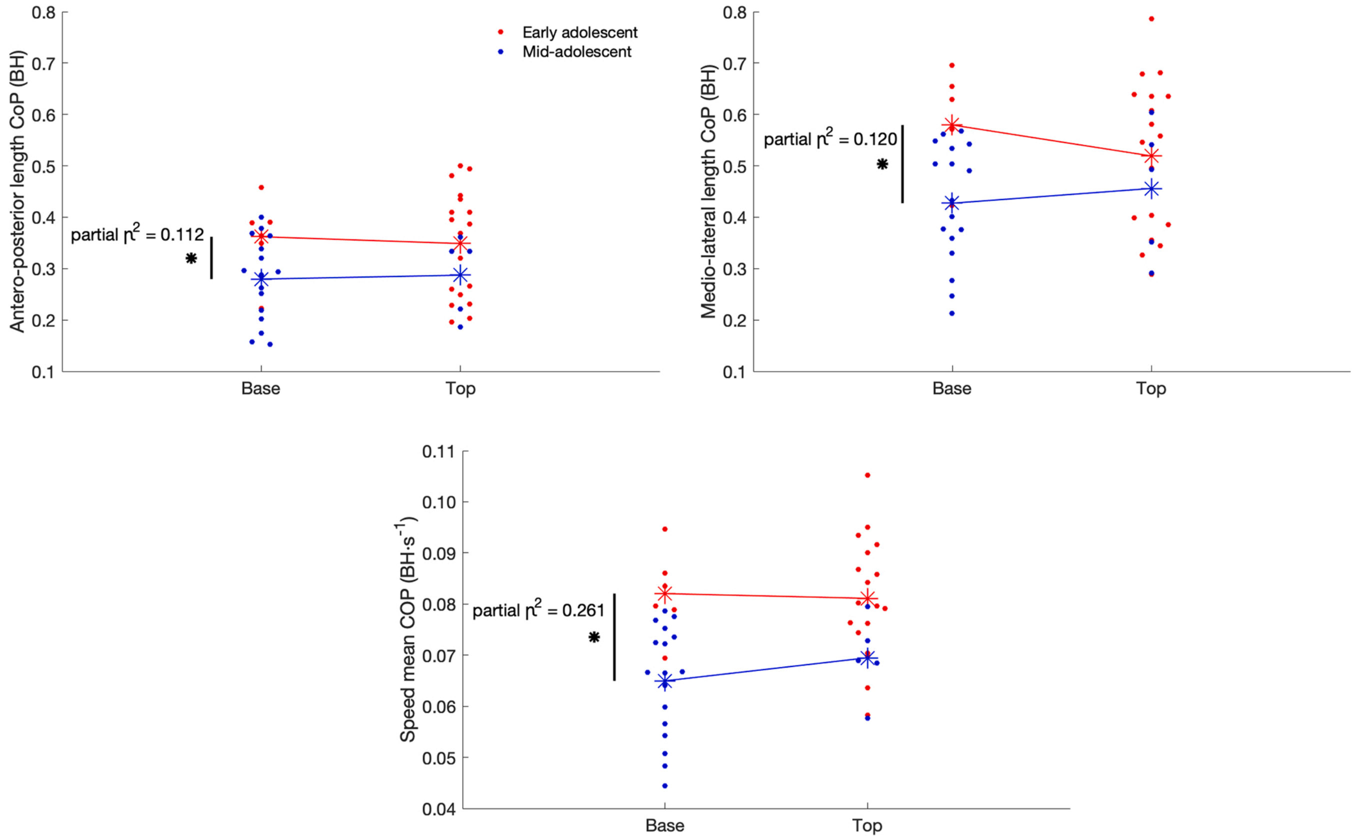

Fig. 5. Headstand test. Individual values and mean of centre of pressure antero-posterior length (top-left), medio-lateral length (top-right), speed mean (bottom), obtained for the 2 roles (Base and Top gymnasts), and the 2 age groups (early and mid-adolescent). CoP measurements normalised relative to body height (BH). * = $p < 0.05$ between age groups; ◊ = $p < 0.05$ between roles.

No interaction between role and age effects was observed in any case ($0.015 \geq F_{1,42} \leq 2.354$, $0.132 \geq p \leq 0.902$).

4. Discussion

The primary aim of this study was to examine the effect of role (base or top) and age (early or mid-adolescent) on static balance in acrobatic gymnasts with different test (generic and specific). As hypothesized, our results showed that the effect of the role affected performance in static balance but was different depending on the test used. Base performed better in unipedal static balance (generic test) than top, in both visual conditions, while there were no differences between roles in headstand (specific test). Moreover, mid-adolescent gymnasts had better postural performance regardless of the task than early adolescent.

Our results have shown a clear effect of age on the static balance capacity in the unipedal stance. Early adolescent gymnasts have poorer performance with higher CoP displacements and speed means, regardless of the role played. A reduction of CoP sway and thus an improvement of postural stability in mid-adolescent could indicate a refinement of regulatory processes in the course of maturation [22]. Although studies with a natural bipedal stance are more common [8,23], similar results have also been reported in balance on one leg [24]. Considering the influence of age observed on the unipedal test, it would be advisable to consider analysing different age groups in future investigations when evaluating the characteristic balance of the gymnasts.

Regarding the effect of age on the CoP excursion in the specific static balance test, a significant influence also has been observed. The current findings align with previous research that reported differences in the postural sway in specific positions (e.g. handstand) when comparing different age groups [9,10], with better results in the more aged gymnasts. To the extent that the base and top gymnasts in our sample are in the same competition category, middle adolescent gymnasts could have more time of practice in the selected specific position. In this sense, the relationship between greater sporting experience and greater performance in specific static positions has been reported [25,26].

Our findings have shown a different static balance profile between the evaluated roles depending on the test analysed. A significant difference was reported in the generic test with better postural performance, with both eyes open and closed, in base versus top gymnasts. Therefore, both visual conditions did not appear to influence the role effect on the standing static balance. Nevertheless, differences were more evident with normal visual conditions, with better static performance in base gymnasts in the three CoP measures analysed. It has been observed that disabling visual control during unipedal test results in an increase in the CoP excursion in both directions and a higher mean CoP speed; logical results taking into account the increased difficulty in the task [27,28]. These differences between roles have not been due to the disparate heights between bases and tops [29], due to the normalization of the CoP outcomes with the height of the participants. Recently, several studies have found evidence of the existence of specific balance profiles based on the role played in the field [4,5]. However, the effect of the role detected in both cases could be conditioned by the evident differences in height between certain positions in the field [4,5]. Our results showed a clear effect on static balance due to specialization according to the role played, once the influence of height has been controlled. These findings agree with the actions carried out by the base gymnast; it may be because these athletes remain static standing for a long duration, holding and balancing the top gymnast, while both jointly performing static pyramids. These actions involve reducing the CoP's displacement to the maximum [15,16], balancing one's own posture and that of the partner. Based on these findings, the static unipedal balance test could be used in the talent identification process of selecting base gymnasts during early specialization, as well as to evaluate and detect high performance base gymnasts.

In contrast, the role played in acrobatic gymnastics did not influence the static balance capacity on the headstand. There were no differences in the base and top groups for the inverted position evaluated, most likely due to this skill being very common in the early stages in Acrobatic Gymnastics, and is practiced by all gymnasts regardless of their role. Although the top gymnast would usually perform various types of handstands on base partner during the pyramids, it does not seem to influence better performance for the inverted position of the headstand by top versus base gymnasts. According to these results, although the headstand can be considered a specific position in acrobatic gymnastics, it has not been shown as a sensitive test to the specific performance between roles. In this line, there is evidence for the absence of transfer between postural capacity displayed by athletes in generic tests against specific tests [1,12,30]. However, more studies are necessary to find tests sensitive to the role played.

Furthermore, there was no interaction between the effect of the role and the effect of age, that is, the effect of the role performed is independent of the effect of age and vice versa. These results may be limited by the reduced difference in age between groups. Greater specialization can be expected as gymnasts increase in age. An adult gymnast (20 years old) could have 6–7 years more experience than the gymnasts in the early adolescent category of the present study. In acrobatic gymnastics it is common for the top to adopt inverted postures more frequently than the base, especially during the execution of pyramids. This circumstance could provide the top to reach a better postural performance than the base in headstand. Therefore, an interaction between age and role could be expected. While the current findings of no difference in the balance performance between base and top in the early adolescent group would be maintained, a better balance performance of the top with respect to the base could appear in a group of adult gymnasts. Further studies are needed to clarify the effects of role played and age on balance performance during a generic and specific postures.

This research was limited to the study of static balance with certain tests, to evaluate the differences between acrobatic gymnastics roles. Given the limited size of certain groups, it is important to encourage further research with more athletes. The results obtained are not transferable to other static positions.

5. Conclusion

The current study has been the first to differentiated performance in static balance according to the role played and age in Acrobatic Gymnastics. The findings have shown the clear effect of age on the static balance manifested in acrobatic gymnastics, regardless of the role played and the test performed. Mid-adolescent athletes presented better control of balance compared to early adolescents, thus athlete age group should be taken into account during the training, evaluation and selection of athletes.

The effect of the role played in this team sport has been different depending on the type of test performed. While the headstand is not sensitive to the role played, the unipedal stance has been best performed by base gymnasts. This test could be used to select or evaluate base gymnasts.

Declaration of Competing Interest

Authors have no conflict of interest and any financial or personal relationships with other people or organizations that could inappropriately influence their work.

Acknowledgments

Funding for open access publishing: Universidad Pablo de Olavide/CBUA. The authors wish to thank the Andalusian Gymnastic Federation by the permission, and specially gymnasts and coaches of the Pyrámidos Club and Acróbatos Club, who gave their time to participate in the study.

References

[1] C. Hrysomallis, Balance ability and athletic performance, Sport. Med. 41 (2011), https://doi.org/10.2165/11538560-000000000-00000.
[2] A. Andreeva, A. Melnikov, D. Skvortsov, K. Akhmerova, A. Vavaev, A. Golov, V. Draugelite, R. Nikolaev, S. Chechelnickaia, D. Zhuk, A. Bayerbakh, V. Nikulin, E. Zemková, Postural stability in athletes: the role of age, sex, performance level, and athlete shoe features, Sports 8 (2020) 1–14, https://doi.org/10.3390/sports8060089.
[3] E. Bressel, J.C. Yonker, J. Kras, E.M. Heath, Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes, J. Athl. Train. 42 (2007) 42–46.
[4] A. Rühlemann, C. Mayer, T. Albrecht, M. Jäger, Functional knee stability in non-elite handball: balance and jump performance differ based on players' position, Knee Surg. Sports Traumatol. Arthrosc. 28 (2020) 1212–1220, https://doi.org/10.1007/s00167-019-05693-y.
[5] Ł. Jadczak, M. Grygorowicz, A. Wieczorek, R. Śliwowski, Analysis of static balance performance and dynamic postural priority according to playing position in elite soccer players, Gait Posture 74 (2019) 148–153, https://doi.org/10.1016/j.gaitpost.2019.09.008.
[6] N. Kirshenbaum, C.L. Riach, J.L. Starkes, Non-linear development of postural control and strategy use in young children: a longitudinal study, Exp. Brain Res. 140 (2001) 420–431, https://doi.org/10.1007/s002210100835.
[7] V. Agostini, E. Chiaramello, L. Canavese, C. Bredariol, M. Knaflitz, Postural sway in volleyball players, Hum. Movement Sci. 32 (2013) 445–456, https://doi.org/10.1016/j.humov.2013.01.002.
[8] E. Verbecque, L. Vereeck, A. Hallemans, Postural sway in children: a literature review, Gait Posture 49 (2016) 402–410, https://doi.org/10.1016/j.gaitpost.2016.08.003.
[9] J. Omorczyk, P. Bujas, E. Puszczałowska-Lizis, L. Biskup, Balance in handstand and postural stability in standing position in athletes practicing gymnastics, Acta Bioeng. Biomech. 20 (2018) 139–147, https://doi.org/10.5277/ABB-01110-2018-02.
[10] M. Sobera, R. Serafin, A. Rutkowska-Kucharska, Stabilometric profile of handstand technique in male gymnasts, Acta Bioeng. Biomech. 21 (2019) 63–71, https://doi.org/10.5277/ABB-01267-2018-02.
[11] E. Zemková, Sport-specific balance, Sport. Med. 44 (2014) 579–590, https://doi.org/10.1007/s40279-013-0130-1.
[12] G. Marcolin, A. Rizzato, J. Zuanon, G. Bosco, A. Paoli, Expertise level influences postural balance control in young gymnasts, J. Sports Med. Phys. Fitness 59 (2019) 593–599, https://doi.org/10.23736/S0022-4707.18.08014-3.
[13] T. Paillard, Relationship between sport expertise and postural skills, Front. Psychol. 10 (2019), https://doi.org/10.3389/fpsyg.2019.01428.
[14] Federation Internationale de Gymnastique, 2017 – 2020 Code of Points Acrobatic Gymnastics, Laussane, 2017.
[15] P. Leal Del Ojo, P. Floría, A.J. Harrison, L.A. Gómez-Landero, Effects of task difficulty on centre of pressure excursion and its inter-trial variability in acrobatic gymnastics pyramid performance, Sport. Biomech. (2020) 1–16, https://doi.org/10.1080/14763141.2020.1770322.
[16] P. Floría, L.A. Gómez-Landero, A.J. Harrison, Centre of pressure correlates with pyramid performance in acrobatic gymnastics, Sport. Biomech. 14 (2015), https://doi.org/10.1080/14763141.2015.1084032.
[17] T. Paillard, F. Noé, Techniques and methods for testing the postural function in healthy and pathological subjects, Biomed Res. Int. 2015 (2015), https://doi.org/10.1155/2015/891390.
[18] L. Chiari, L. Rocchi, A. Cappello, Stabilometric parameters are affected by anthropometry and foot placement, Clin. Biomech. 17 (2002) 666–677, https://doi.org/10.1016/S0268-0033(02)00107-9.
[19] K.A. Ball, R.J. Best, T.V. Wrigley, Body sway, aim point fluctuation and performances in rifle shooters: inter- and intra-individual analysis, J. Sports Sci. 21 (2003) 559–566, https://doi.org/10.1080/0264041031000101881.
[20] A. Ruhe, R. Fejer, B. Walker, The test-retest reliability of centre of pressure measures in bipedal static task conditions - A systematic review of the literature, Gait Posture 32 (2010) 436–445, https://doi.org/10.1016/j.gaitpost.2010.09.012.
[21] J. Cohen, Statistical Power Analysis for the Behavioral Sciences, 2nd ed., Erlbaum, Hillsdale, NJ, 1988.
[22] O. Ludwig, J. Kelm, A. Hammes, E. Schmitt, M. Fröhlich, Neuromuscular performance of balance and posture control in childhood and adolescence, H eliyon 6 (2020) 1–11, https://doi.org/10.1016/j.heliyon.2020.e04541.
[23] L. Nolan, A. Grigorenko, A. Thorstensson, Balance control: sex and age differences in 9- to 16-years-olds, Dev. Med. Child Neurol. 47 (2005) 449–454, https://doi.org/10.1017/S0012162205000873.
[24] D. Kevin, S. Filip, P. Kathelijne, V.G. Kristel, H. Cedric, L. Sebastien, Postural control of typical developing boys during the transition from double-leg stance to single-leg stance, Eur. J. Pediatr. 176 (2017) 273–278, https://doi.org/10.1007/s00431-016-2829-0.
[25] G. Croix, D. Chollet, R. Thouvarecq, Effect of expertise level on the perceptual characteristics of gymnasts, J. Strength Cond. Res. 24 (2010) 1458–1463.
[26] G. Gautier, L. Marin, D. Leroy, R. Thouvarecq, Dynamics of expertise level: coordination in handstand, Hum. Movement Sci. 28 (2009) 129–140, https://doi.org/10.1016/j.humov.2008.05.003.

[27] E. Puszczałowska-Lizis, J. Omorczyk, The level of body balance in standing position and handstand in seniors athletes practicing artistic gymnastics, Acta Bioeng. Biomech. 21 (2019), https://doi.org/10.5277/ABB-01352-2019-02.

[28] F. Reynard, D. Christe, P. Terrier, Postural control in healthy adults: determinants of trunk sway assessed with a chest-worn accelerometer in 12 quiet standing tasks, PLoS One 14 (2019) 1–17, https://doi.org/10.1371/journal.pone.0211051.

[29] Y. Taboada-Iglesias, Á. Gutiérrez-Sánchez, M.V. Santana, Anthropometric profile of elite acrobatic gymnasts and prediction of role performance, J. Sports Med. Phys. Fitness 56 (2016) 433–442.

[30] F. Asseman, O. Caron, J. Crémieux, Is there a transfer of postural ability from specific to unspecific postures in elite gymnasts? Neurosci. Lett. 358 (2004) 83–86, https://doi.org/10.1016/j.neulet.2003.12.102.