THE EFFECTIVENESS OF DIFFERENT HANDSTAND PLACEMENT TECHNIQUES IN HANDSTAND BALANCE CONTROL AND GENDER DIFFERENCES

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Abstract
The purpose of the study was twofold: (a) to examine the impact of various finger placements and utilization on the quality, control, and overall efficiency of handstand performance, and (b) to investigate potential gender differences in relation to these factors. Thirty-one young competitive gymnasts (15 males; age: 12.60 ± 2.08, and 16 females; age: 13.31 ± 2.21) participated in this study. A portable posturographic digital platform was used to record hand area (cm²), maximal pressure (kPa), CoP (center of hand pressure) sway area (mm²), CoP linear distance displacement (mm) and CoP velocity. Derived data were analyzed in an integrated software module (Foot Checker, version 4.0). The intra-class correlation coefficient and the coefficient of variation supported the reliability of the measurements. One-way MANOVA showed better balance control for all gymnasts for the handstand with flat palms and joined and fully stretched fingers, followed by that of flat palms and wide open and fully stretched fingers, and wide flat palms and open and flexed fingers. Results from one-way MANOVA indicated no differences between males and females in age, training age, body mass, height, and body mass index. With control for the effects of age, training age, personal characteristics and hand area of support in place, females had better balance control compared to males based on differences in CoP sway area, CoP linear distance displacement, and CoP velocity. Despite the study's limitations, the findings contribute to the existing literature on balance control techniques in handstands in relation to gender differences. The study provides recommendations for more effective training for coaches and suggests avenues for future research.

Keywords: *handstand, balance control, artistic gymnastics, males, females.*

INTRODUCTION

The handstand is a non-acrobatic skill (element), in which the body of the gymnast is maintained in the equilibrium position with all parts aligned vertically, with the hands pressed onto the floor or another apparatus (MAG; WAG, Code of points, Fédération Internationale de Gymnastique, 2020a, b). The handstand is considered a fundamental gymnastics skill for both male and female gymnast because it plays a crucial role in the quality and safety of gymnastics skill execution and the potential of gymnasts to develop and perform at a high level (Hedbávný, Sklenaříková, Hupka, & Kalichová, 2013; Uzunov, 2008; Živčić-Marković, Krističević, & Aleksić-Veljković, 2015). Maintaining balance in an error-free, and thus, stable manner during the handstand was the issue examined by several authors (Omorczyk, Bujas, Puszczałowska-Lizis, & Biskup, 2018; Slobonov & Newell, 1996; Sobera, Siedlecka, Piestrak, Sojka-Krawiec, & Graczykowska, 2007).

Performing a handstand with quality and balance control is more challenging biochemically when compared to an upright position. This is due to several factors: the smaller area of support provided by the palms and fingers, the increased distance between the base of support and the center of mass (CoM), and the lower and inverted position of the head (Hedbávný et al., 2013; Slobounov & Newell, 1996; Sobera, Serafin, & Rutkowska-Kucharska, 2019). To maintain balance in a handstand, it necessitates the coordination of various muscles involved in joint movements, such as wrists, elbows, shoulders, and hips; the management of different body shapes, and the control of the movement of the CoM (Blenkinsop, Pain, & Hiley, 2017; Gautier, Thouvarecq, & Chollet, 2007; Kerwin & Trewartha, 2001; Slobounov & Newell, 1996; Uzunov, 2008; Yedon & Trewartha, 2003). This entails maintaining a properly aligned body shape and balancing it over the wrists, employing a cohesive approach known as the "wrist strategy" (Hedbávný et al., 2013; Kerwin & Trewartha, 2001; Kochanowicz, Niespodziñski, Mieszkowski, Kochanowicz, & Sawczyn, 2018; Rohleder & Vogt, 2018; Slobounov & Newell, 1996; Uzunov, 2008; Yeadon & Trewartha, 2003). The equilibrium in the handstand primarily relies on the strength of the arm muscles and the adjustment of finger pressure on the supporting surface. This compensation occurs when the CoM shifts towards the fingers, necessitating increased pressure at the base of support, or when the CoM moves towards the wrist joints, necessitating heightened pressure beneath these joints (Gautier et al., 2007; Kerwin & Trewartha, 2001; Sobera et al., 2007; Slobounov & Newell, 1996; Yedon, & Trewartha, 2003).

Gymnasts may choose to place their fingers fully stretched and joint (it is possible for beginners), fully stretched or with the slightest bit of distributed flexion, or to use a tented/cambered/spider finger position where the distal interphalangeal joint and proximal interphalangeal joint are flexed. It has been suggested that the placement with outstretched tented/cambered/spider fingers is more effective. This technique allows gymnasts to generate more tension, exert greater pressure on the floor, and make more precise corrections to counterbalance during the posterior body tilt (falling over) (Bessi, 2009; George, 1980; Rohleder & Vogt, 2018). This approach is recommended as a more effective method for gymnasts to execute a handstand with proper form and balanced control. By positioning their weight over their fingers instead of the palm, gymnasts can avoid technical errors such as elbow bending, shoulder extension, and hip flexion, which are necessary for countering the forward tilt when descending (George, 1980). However, there is currently a lack of research supporting these recommendations regarding the various finger placements.

Research suggests that balance control in handstands is influenced by gymnasts' ability to manipulate the displacement and velocity of their (CoM) (Omorczyk et al., 2018). This control primarily relies on torque applied from the wrists, with support from the shoulders and hips (Kerwin & Trewartha, 2001; Rohleder & Vogt, 2018; Yeadon & Trewartha, 2003). This means that the displacement of the CoP towards the fingers or the wrist joint in the sagittal plane plays a decisive role in regulating the balance during handstand. Therefore, assessing stability and performance parameters should include measuring the sway signal of the CoP using pressure or force assessment systems (Scoppa, Capra, Gallamini, & Shiffer, 2013). The CoP represents the point where vertical forces interact with the supporting surface and determines the overall effectiveness of the postural control system and gravity (Duarte & Zatsiorsky, 2000). The area of CoP sway serves as an indicator of a gymnast's performance while attempting to maintain balance in a handstand, with smaller sway surfaces indicating better performance. Additionally, the mean velocity of the CoP indicates the fluctuation in muscular force and can be used to assess balance control, with lower velocity values reflecting higher quality balance control in handstands (Asseman, Caron, & Crémieux, 2005).

The impact of gender on balance performance and balancing strategies has been a subject of interest among researchers (Hedbávný et al., 2013). Research exploring the influence of gender on balance control has found that, in comparison to girls, boys:

(a) Showed signs of being less attentive and more agitated under the age of 10 years (Odenrick & Sandstedt, 1984; Riach & Hayes, 1987; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006) and exhibited more swaying (Hirabayashi & Iwasaki, 1995; Riach & Hayes, 1987). (b) Demonstrated inferior balance performance across most age groups, except for 8-year-olds (Holm & Vøllestad, 2008). (c) Displayed greater center of pressure excursion during one-legged tasks between the ages of 7-11 years (Lee & Lin, 2007) and 12-15 years (Milosis & Siatras, 2012). (d) Achieved lower scores in a composite score calculated from six different test conditions at the age of 11-12 years (Steindl et al., 2006).

Conversely, research results (Eguchi & Takada, 2014; Smith, Ulmer, & Wong, 2012; Steindl et al., 2006) affirm that, compared to boys of the same age, girls exhibit better balance performance, enhanced sensory integration (Steindl et al., 2006), advanced neuromuscular development (Eguchi & Takada, 2014), lower levels of hyperactivity (Hirabayashi & Iwasaki, 1995), and employ more adult-like postural control strategies (Smith et al., 2012). Furthermore, females tend to show a greater rate of improvement in stability until the age of 11-12 years and enter the adult range of stability earlier than boys. Conversely, males appear to have a greater rate of improvement in stability as they age compared to females (Riach & Hayes, 1987).

However, some researchers speculate that girls and boys perform equally well in terms of balance control (Butz, Sweeney, Roberts, & Rauh, 2015; Libardoni et al., 2017). Some studies produced inconsistent results (Kejonen, 2002; Peterson, Christou, & Rosengren, 2006; Steindl et al., 2006), although different instruments and procedures were used making it difficult to generalize the results (Kejonen, 2002). Therefore, it has not been confirmed with certainty whether there are differences between the two genders regarding balance control, in what way, to what extent, and under what conditions.

Gymnastic training plays a vital role in developing balance control and achieving exceptional stability, even in challenging positions like the handstand. When it comes to the handstand skill in gymnastics, the Code of Points (MAG; WAG, 2020a, b) outlines slightly different requirements for men and women. Specifically, a momentary handstand is required as a skill for: (a) Female gymnasts as early as 7-8 years old, for the balance beam and floor exercise, and 11-12 years old for the single bar. (b) Male gymnasts starting at 8-9 years old for the floor exercise and 10-11 years old for the parallel bars exercise.

Moreover, static handstand skills are mandated for males starting at the age of 12-13 for the floor, rings, and parallel bars exercises. Handstand performance displays both commonalities and variations between males and females, influenced by differences in apparatuses. For instance, the handstand serves as a foundational component within broader motor sequences for both genders, such as executing forward or backward handsprings on the floor or vault. Additionally, it is a crucial element in various gymnastic skills, including transitioning with straight arms into a handstand (e.g., from a long hand swing, a free hip circle, or a cast) on horizontal bars and uneven bars.

In contrast, the handstand is employed differently on the balance beam (e.g., jump, press, or swing to handstand, kick to the side or cross handstand (2sec), backward roll to handstand, cartwheel), rings (e.g., swing to handstand, press to handstand), pommel horse (e.g., scissor through handstand), and parallel bars (e.g., executing a basket or a giant swing to handstand).

On the other hand, the assessment of strength, power, and endurance for males and females includes activities such as press to handstand and handstand hold on parallel bars, rings, and balance beam (Fink, Hofmann, & Scholtz, 2021; Fink, Lopez, &, Hofmann, 2021). These gender-specific differences, especially within the age group development, lead to deliberate training specifically designed for different apparatus for male and female gymnasts. This training can potentially cause long-term differences in balance control and regulation during handstands between the two genders.

Considering that the handstand is one of the most important fundamental skills of gymnastics, decoding motor behavior in handstands has received considerable attention in recent research (Blenkinsop et al., 2017; Gautier et al., 2007; Kerwin & Trewartha, 2001; Kochanowicz et al., 2018; Omorczyk et al., 2018; Sobera et al., 2007) in the available technical and scientific literature (George, 1980; Hedbávný et al., 2013; Kerwin, & Trewartha, 2001; MAG, 2020; Uzunov, 2008; Yedon, & Trewartha, 2003; Živčić-Marković et al., 2015).

However, there is a lack of studies investigating the performance of gymnasts in handstands using different palm/finger placements and activation methods, as well as potential differences in balance control between male and female gymnasts. The objective of this study was to examine the effectiveness of three distinct hand placement and activation methods in regulating handstands, both for the entire sample and separately for male and female gymnasts.

Specifically, we investigated differences between the following variations in hand placement:

(a) Flat palms, wide-open and flexed fingers (also known as spider fingers or tented fingers).

(b) Flat palms, wide-open and fully stretched fingers.

(c) Flat palms, joined and fully stretched fingers (as shown in Figure 1).

These variations were assessed for all gymnasts and separately for male and female gymnasts. Additionally, we examined differences in balance control and regulation during handstands between male and female gymnasts while considering the three different techniques of finger placement and activation. We controlled for the effects of age and personal characteristics.

Hypotheses derived from the literature review suggested that utilizing hand placement characterized by flat palms, wide-open, and flexed fingers would optimize handstand performance. Based on existing research findings and study design factors (e.g., age and training experience of the gymnasts), we anticipated that female gymnasts would demonstrate superior balance control in handstands compared to their male counterparts.

METHODS

Participants

Thirty-one young competitive gymnasts (15 males and 16 females) without any medical or orthopedic problems volunteered and participated in the study (Table 1). A sample of 31 gymnasts can provide a power of 0.80 to detect differences between genders using an alpha of 0.05 and medium to large effect size ($\eta^2 > 0.25$) (G*Power 3.1.9.7). Only gymnasts who were able to maintain a static base of support with an aligned body shape for a minimum of 10 seconds during a handstand were included in the study. All gymnasts had 4 to 11 years' experience of structured training and competitive gymnastics at the national level. Young gymnasts acquire the ability to freely maintain static body balance in handstand on a flat surface, such as floor, usually after 3-4 years of specific gymnastics training (Kochanowicz, Kochanowicz, Niespodziński, Mieszkowski, & Biskup, 2015). All gymnasts who participated in the study trained six times a week for about three hours each afternoon on weekdays and on Saturday morning. The gymnasts trained and competed on every apparatus (floor, horse, rings, vault, parallel bars, horizontal bar for males, and vault, uneven bars, beam, floor for females).

All gymnasts participating in this study were exclusively dedicated to gymnastics and did not engage in other sports activities. They also attended two hours of physical education classes per week at their public school.

In accordance with the ethical guidelines established by the Ethical Committee of Aristotle University of Thessaloniki, comprehensive information regarding the study's purpose and testing procedures was provided to the parents, coaches, and gymnasts. The parents of the gymnasts granted written consent before measurements were conducted.

Data collection

The distribution of weight and the stability in handstand steadiness was recorded and analyzed on a vertical posturographic digital platform (Foot Checker, Comex S.A./LorAn Engineering Srl; Castel Maggiore, Bologna, Italy). This floor-positioned instrument, measuring 700 X 500mm, contained 2304 resistive sensors with a measurement accuracy of .001 kPa, sampled at a frequency of 60 Hz. Hand area (cm^2), maximal pressure (the amount of force acting vertically on the surface of the support; kPa), center of pressure (CoP) sway area (defined as an ellipse containing 90% of all displacement points; mm^2), CoP linear distance displacement (LDD; a measure of both the distance and direction that CoP travels; mm), and CoP mean velocity (sum of the cumulated CoP displacement divided by the total time; mm/s), were analyzed using an integrated software module (Foot Checker, version 4.0).

Procedures

All participants were subjected to identical experimental conditions during all measurements. These tests were conducted by the same researcher in a controlled environment to minimize distractions. The portable platform was positioned in a designated area. All measurements were taken in the afternoon, prior to the start of the training session, to mitigate the potential influence of training fatigue on the results.

The measurements focused on the 'press to handstand hold' technique, which began with participants in a standing position, feet apart, and hands placed shoulder-width apart on the platform. Participants received specific instructions for hand placement, as follows:

(a) Place your hands with flat palms, wide open, and flexed fingers (also known as spider fingers or tented fingers) to ensure that the palm of the hand, the first knuckle of all fingers, and the fingertips are in contact with the floor. (b) Place your hands with flat palms, wide open, and fully stretched fingers so that the entire surface of the fingers touches the floor. (c) Place your hands with flat palms, joined and fully stretched fingers so that the entire surface of the fingers touches the floor (as illustrated in Figure 1).

Participants were also instructed to maintain parallel index fingers pointing forward in all conditions. Following a brief warm-up, all participants familiarized themselves with the testing protocol and practiced the three variations of the press to handstand hold.

Subsequently, participants were instructed to perform a press to handstand hold for a minimum of 10 seconds while maintaining stillness with their eyes open on the platform. Each test was conducted in a random order, with a two-minute rest period between trials. An experimenter provided assistance by lightly touching the sides of the gymnast's upper legs to help them achieve a stable handstand position with proper body alignment. Once the stable handstand was attained, the legs were released, and the assessment was carried out and recorded for a duration of 10 seconds.The reason for choosing this specific duration for the handstand was based on the research-backed evidence that suggests a decline in stability beyond a 15-second handstand (Slobounov & Newell, 1996). Throughout all trials, the gymnasts were instructed to maintain a static base of support; attempt to remain still using their wrists and fingers; fixate their gaze in front of their wrists in the space between their hands (Asseman et al., 2005); keep their head in a neutral position (Asseman et al., 2005), and maintain straight arms, and body as tight, strong, and still as possible. Specifically, the participants were instructed to press their fingertips vertically into the floor to push the body weight back if they were falling forward in the handstand, and to push the palms of the hands onto the floor and lift the fingers off the floor to shift the body weight forward if they were falling backwards. Any change to the base of support, such as a shuffle or step, or a fall before completing at least 10 seconds in a stable handstand, was considered a failure to maintain balance, leading to the termination of the trial.

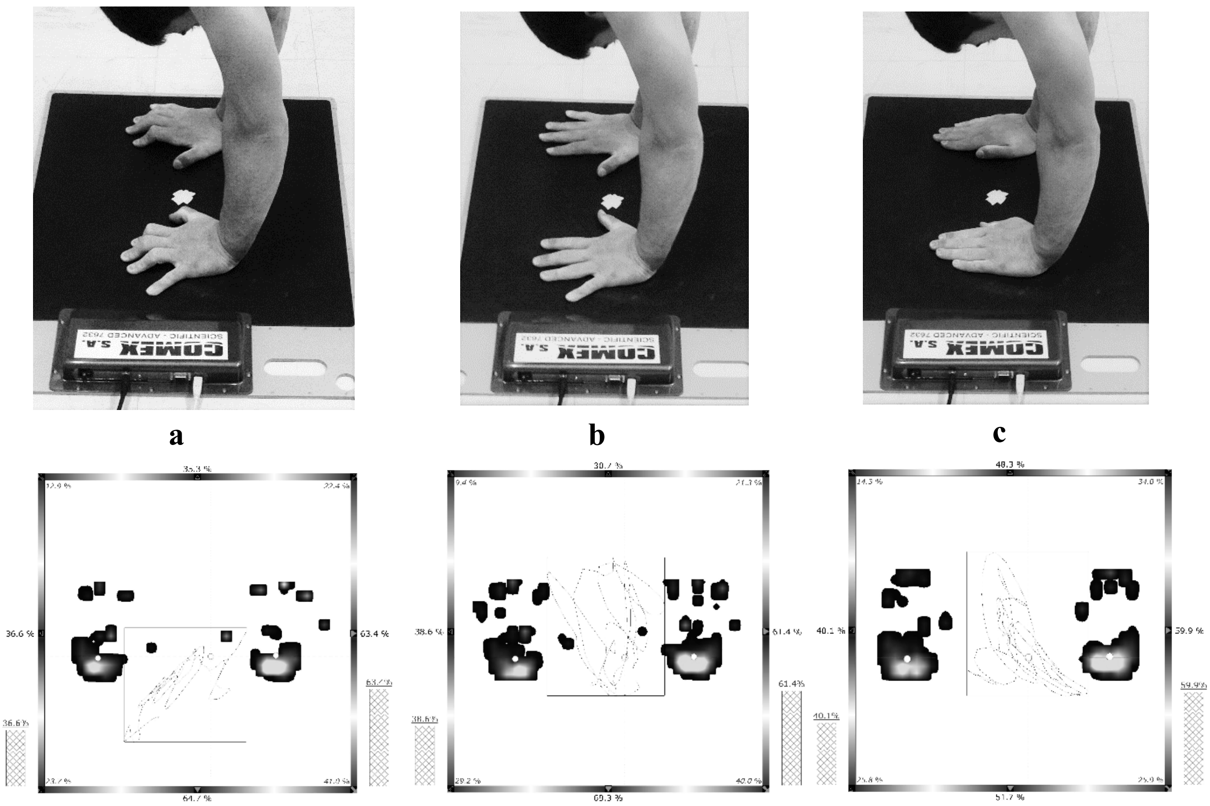

Figure 1: The hand placement on the platform located above and the graphical illustration displayed below: (a) flat palms with wide open and flexed fingers (also known as spider fingers or tended fingers); (b) flat palms with wide open and fully stretched fingers, and (c) flat palms with joined and fully stretched fingers.

Statistical analyses

All statistical analyses were performed using the SPSS software (SPSS v. 28, SPSS Statistics, IBM Corp., NY). The Shapiro-Wilk test was used to test the normality of the data. A *p* value less than 0.05 was considered significant. To verify the reliability of the measurements, all tests were repeated twice (test-retest), under the same conditions by the same experienced examiner, within a one-week period. The test-retest reliability was examined using the intra-class correlation coefficient (ICC), based on a one-way ANOVA that compares within-subject variability and between-subject variability. One-way multivariate analysis of variance (MANOVA) was applied to examine the effect of the three different techniques of hand placement on balance control during a handstand. To identify significant differences in the dependent variables, multiple univariate ANOVAs with Bonferroni correction were conducted, followed by post hoc analyses with pairwise comparisons between groups for the statistically significant univariate ANOVAs. One-way MANOVA was used to examine age, training age, body mass, height, and body mass index (BMI) differences between male and female gymnasts. One-way multivariate analyses of covariance (MANCOVA) were performed to determine statistically significant differences between male and female gymnasts in handstand steadiness variables while controlling for gymnasts' age and personal characteristics. Age and personal characteristics (e.g., body mass, height, BMI) have been used as factors that affect the human balance system (Faraldo-García, Santos-Pérez, Crujeiras-Casais, Labella-Caballero, & Soto-Varela, 2012; Liaw et al., 2009; Olchowik, 2015). Firstly, differences in the hand area of the left hand (HALH; cm²) and the hand area of the right hand (HARH; cm²) between the two genders were examined, with gymnasts' age and personal characteristics as covariates. Then, the differences between the two genders in (a) maximal pressure of the left hand (MPLH; kPa), (b) maximal pressure of the right hand (MPRH; kPa), (c) center of pressure (CoP) sway area (mm²), (d) CoP linear distance displacement (mm), and (e) CoP velocity (mm/s) were evaluated. In these MANCOVAS the variables gymnasts' age, training age, body mass, height, BMI, HALH, and HARH were used as covariates.

RESULTS

Assumptions and reliability of the measurements

The independent variables satisfy the criteria for a normal distribution. The skewness (-1.0 to +1.0) and the kurtosis (-1.6 to +1.6) of the distribution, and the Shapiro-Wilk test provided support for the normal distribution of all variables (p >.05). The Box's test provided support for the equality of variance-covariance matrices across groups. The results of the Bartlett's test of sphericity confirmed that the variances were equal across groups, and the Levene's test provided support for the equality of error variance across groups ($p > .05$). The single measures intra-class correlation coefficient values ranged from .62 to .95 for males, and from .64 to .93 for females (Tables 2, 3).

Differences between handstand variations

For all gymnasts (both genders). The one-way multivariate analysis of variance (MANOVA) yielded a multivariate main significant effect for handstand with different hand placement, Wilks' $\lambda = .378$, $F(7,14) = 7.51$, $p < .001$, $\eta^2 = .39$. The ANOVAs performed on each of the dependent variables revealed significant effects for handstand with different hand placement on all the dependent variables. Finally, a series of post-hoc analyses were performed to examine individual mean difference comparisons across all three handstand variations and all seven dependent variables. The results are illustrated in Table 1.

For male gymnasts. The one-way multivariate analysis of variance (MANOVA) yielded a multivariate main significant effect for handstand with different hand placement, Wilks' $\lambda = .183$, $F(7,14) = 6.89$, $p < .001$, $\eta^2 = .57$. The ANOVAs conducted on each of the dependent variables revealed significant effects for handstand with different hand placement on the dependent variables MPLH, MPRH, CoP sway area, and CoP LDD. Finally, a series of post-hoc analyses were carried out to examine individual mean difference comparisons across all three handstand variations and all seven dependent variables. The results are presented in Table 1.

For female gymnasts. The one-way multivariate analysis of variance (MANOVA) yielded a multivariate main significant effect for handstand with different hand placement, Wilks' $\lambda = .448$, $F(7,14) = 2.75$, $p < .01$, $\eta^2 = .33$. The ANOVAs conducted on each of the dependent variables revealed significant effects for handstand with different hand placement on the dependent variables HALH, HARH MPLH, CoP sway area, and CoP LDD. Finally, a series of post-hoc analyses were carried out to examine individual mean difference comparisons across all three handstand variations and all seven dependent variables. The results are shown in Table 4.

Gender differences

Gymnasts' characteristics. The one-way multivariate analysis of variance (MANOVA) yielded a main effect for gender, Wilks' $\lambda = .605$, $F(5,25) = 3.26$, $p = .021$, $\eta^2 = .40$. However, as shown in Table 1, the univariate analyses of variance (ANOVAs) that followed indicated that the between-subjects effects were not statistically significant for all the examined variables (age, training age, body mass, height, and BMI).

Gymnasts' hand area in the handstand. The one-way multivariate analysis of covariance (MANCOVA) showed significant effect of the covariate age, Wilks' $\lambda = .552$, $F(6,19) = 2.57$, $p = .054$, $\eta^2 = .45$. In addition, after controlling for the effects of covariates, the multivariate main effect of gender on the dependent variables was not significant, Wilks' $\lambda = .584$, $F(6,19) = 2.26$, $p = .082$, $\eta^2 = .42$. The ANOVAs conducted on each of the dependent variables revealed significant differences between male and female gymnasts for the variables HALH-HOFF, HARH-HOFF, HALH-HOSF, HALH-HJSF, and HARH-HJSF. Comparing the estimated marginal means showed that males had higher scores compared to females (Table 3).

Table 1

Results of one-way MANOVA for all dependent variables between handstand variations

	All gymnasts							
	HOFF (a)		HOSF (b)		HJSF (c)			
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η²
HALH	46.98**c**	12.06	54.02	13.01	57.60**a**	13.47	5.46**	.11
HARH	47.87**bc**	11.52	56.40**a**	13.12	59.56**a**	14.73	6.52**	.13
MPLH	206.91**c**	19.91	193.72**c**	21.14	170.86**ab**	27.94	18.14***	.29
MPRH	217.05**c**	12.49	210.28	17.03	202.20**a**	21.65	5.62**	.11
CoP sway area	1143.85**c**	544.02	930.64**c**	458.37	622.23**ab**	270.26	11.05***	.20
CoP LDD	367.53**bc**	120.84	296.74**a**	91.29	289.36**a**	92.13	5.51**	.11
CoP velocity	36.26**c**	11.88	31.33	9.54	29.67**a**	9.76	3.32*	.07
	Male gymnasts							
	HOFF (a)		HOSF (b)		HJSF (c)			
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η²
HALH	50.47**c**	13.54	55.97	15.62	62.00**a**	16.37	2.15	.09
HARH	52.30**c**	13.09	58.87	15.26	64.37**a**	18.81	2.17	.09
MPLH	207.02**c**	22.09	193.48**c**	21.93	170.24**ab**	23.49	10.24***	.33
MPRH	213.97**c**	12.31	200.65	18.50	194.58**a**	18.12	5.39**	.20
CoP sway area	1470.73	495.78	1202.52	383.88	768.11	220.32	12.81***	.38
CoP LDD	438.01**bc**	87.26	357.01**a**	55.97	358.70**a**	77.31	5.77**	.22
CoP velocity	42.64	9.14	37.56	7.28	36.73	8.32	2.24	.10
	Female gymnasts							
	HOFF (a)		HOSF (b)		HJSF (c)			
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η²
HALH	43.72**bc**	9.79	52.19**a**	10.17	53.47**a**	8.67	4.91**	.18
HARH	43.72**bc**	8.21	54.09**a**	10.73	55.06**a**	7.69	7.85***	.26
MPLH	206.80**c**	18.37	193.93**c**	21.09	171.44**a**	34.78	7.72***	.26
MPRH	219.93	12.34	219.31	9.00	216.19	12.25	2.26	.09
CoP sway area	837.40**c**	394.32	675.76	373.43	485.45**a**	243.57	4.21*	.16
CoP LDD	301.45**c**	111.70	240.22	81.89	255.35**a**	88.97	3.74*	.14
CoP velocity	30.27**c**	11.18	25.50	7.59	23.05**a**	5.43	3.05	.12

Abbreviations: HOFF, handstand with open and flexed fingers; HOSF, handstand with open and fully stretched fingers; HJSF, handstand with joined and fully stretched fingers; HALH, hand area of the left hand; HARH, hand area of the right hand; MPLH, maximal pressure of the left hand; MPRH, maximal pressure of the right hand.

The index in boldface below the means indicates statistically significant differences between the respective variables.

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

Table 2

Results of a one-way MANOVA for male and female gymnasts' characteristics

	Males		Females			
	M	*SD*	*M*	*SD*	*F*	η²
Age	12.60	2.08	13.31	2.21	.85	.03
Training age	6.33	2.38	7.44	2.31	1.72	.06
Body mass	37.80	10.31	39.93	7.07	.46	.02
Height	144.07	13.04	150.88	7.47	3.23	.10
BMI	17.83	1.97	17.41	1.85	.37	.01

Abbreviations: BMI, body mass index (body mass/height²); M, mean; SD, standard deviation, F, significant differences; η², magnitude of difference between the two means.
**p < .05, **p < .01, ***p < .001*

Table 3

Results of one-wway MANCOVAs and ICC for hand area between male and female gymnasts

	Males			Females				
	M	*SE*	ICC	*M*	*SE*	ICC	*F*	η²
HALH-HOFF	51.68	2.50	.92	42.59	2.41	.93	5.51*	.19
HARH-HOFF	53.03	2.05	.88	43.03	1.97	.75	9.98**	.29
HALH-HOSF	57.48	2.27	.93	50.77	2.18	.77	3.64	.13
HARH-HOSF	60.75	2.37	.88	52.33	2.28	.70	5.26*	.18
HALH-HJSF	63.42	2.50	.95	52.14	2.40	.72	8.54**	.26
HARH-HJSF	68.32	2.81	.66	51.36	2.70	.73	15.16***	.39

Abbreviations: M, mean; SE, standard error of the mean; ICC, intraclass correlation coefficient; HALH-HOFF, hand area of the left hand; HOFF, handstand with wide open and flexed fingers; HARH, hand area of the right hand; HOSF, handstand with wide open and fully stretched fingers; HJSF, handstand with joint and fully stretched fingers.
The variables gymnasts' age, training age, body mass, height, and BMI were used as covariates.

Handstand with wide open and flexed fingers. The one-way multivariate analysis of covariance (MANCOVA) showed that the effect of the covariates was not significant. However, there was a significant multivariate main effect of gender after controlling for the effects of covariates on the dependent variables, Wilks' $\lambda = .513$, $F(5,18) = 4.02$, $p = .013$, $\eta^2 = .53$. However, the ANOVAs conducted on each of the dependent variables revealed significant differences between male and female gymnasts for the variables CoP sway area and CoP LDD. Comparing the estimated marginal means showed that males had higher scores compared to females (Table 4).

Handstand with wide open and fully stretched fingers. The one-way multivariate analysis of covariance (MANCOVA) showed that the effect of the covariates was not significant. In addition, after controlling for the effects of covariates, the multivariate main effect of gender on the dependent variables was not significant, Wilks' $\lambda = .625$, $F(5,18) = 2.16$, $p = .105$, $\eta^2 = .38$. However, the ANOVAs performed on each of the dependent variables revealed significant differences between male and female gymnasts for the variables CoP sway area, CoP LDD, and CoP velocity. Comparing the estimated marginal means showed that males had higher scores compared to females (Table 4).

Handstand with closed and fully stretched fingers. The one-way multivariate analysis of covariance (MANCOVA) showed that the effect of the covariates was not significant. In addition, after controlling for the effects of covariates, the multivariate main effect of gender on the dependent variables was not significant, Wilks' λ = .811, $F(5,18) = .84$, $p = .540$, $\eta^2 = .19$. The ANOVAs performed on each of the dependent variables revealed significant differences between male and female gymnasts only for the variable CoP LDD. Comparing the estimated marginal means showed that males had higher scores compared to females (Table 4).

Table 4

Results of one-way MANCOVAs and ICC for all dependent variables between male and female gymnasts

	Handstand with wide open and flexed fingers (HOFF)							
	Males			Females				
	M	*SE*	ICC	*M*	*SE*	ICC	*F*	η²
MPLH	213.30	7.16	.77	200.92	6.84	.64	1.11	.30
MPRH	217.36	3.77	.62	216.76	3.45	.65	.01	.00
CoP sway area	1518.72	159.71	.81	792.41	156.65	.73	7.71**	.26
CoP LDD	440.59	33.46	.78	299.03	31.98	.76	6.68*	.23
CoP velocity	42.11	3.43	.72	30.77	3.28	.77	4.08	.16
	Handstand with wide open and fully stretched fingers (HOSF)							
	Males			Females				
	M	*SE*	ICC	*M*	*SE*	ICC	*F*	η²
MPLH	197.17	7.40	.71	190.47	7.09	.73	.32	.01
MPRH	207.62	3.49	.69	212.77	3.34	.66	.85	.04
CoP sway area	1195.42	133.56	.84	682.42	127.92	.69	5.76*	.21
CoP LDD	357.67	21.73	.72	239.61	20.81	.69	11.52**	.34
CoP velocity	37.19	2.51	.62	25.84	2.41	.69	7.96**	.27
	Handstand with joined and fully stretched fingers (HJSF)							
	Males			Females				
	M	*SE*	ICC	*M*	*SE*	ICC	*F*	η²
MPLH	175.46	9.21	.72	166.55	8.79	.77	.34	.02
MPRH	199.49	6.72	.73	204.74	6.41	.84	.22	.01
CoP sway area	672.84	75.99	.74	574.77	72.50	.91	.60	.03
CoP LDD	324.77	19.65	.71	256.17	18.75	.66	4.38*	.17
CoP velocity	33.23	2.40	.72	26.34	2.29	.63	2.97	.12

Abbreviations: MPLH, maximal pressure of the left hand; MPRH, maximal pressure of the right hand; CoP, center of pressure; LDD, linear distance displacement.
The variables gymnasts' age, training age, body mass, height, and BMI, HALH-HOFF and HARH-HOFF for HOFF, HALH-HOSF and HARH-HOSF for HOSF, and HALH-HJSF and HARH-HJSF for HJSF were used as covariates.
$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

DISCUSSION

The aim of the present study was to evaluate the effectiveness of different techniques regarding hand placement in handstand control and regulation. Additionally, gender differences in handstand performance were examined. Previous research has suggested that hand placement tented/cambered/spider fingers is more effective. This approach allows gymnasts to generate greater tension, exert more pressure on the floor, and make more precise corrections to prevent falling over (Bessi, 2009; George, 1980; Rohleder & Vogt, 2018). The findings of the present study do not align with either the aforementioned recommendations or the study hypothesis regarding the most effective hand placement for improved performance during a handstand. Despite gymnasts applying more pressure, especially on the left hand, during a handstand with wide open and flexed fingers compared to a handstand with open and fully stretched fingers and a handstand with joined and fully stretched fingers, this did not result in better handstand control.

The results showed a consistent pattern among both male and female gymnasts, with more effective control and regulation observed in the handstand with joined and fully stretched fingers, followed by the handstand with open and fully stretched fingers, and finally the handstand with wide open and flexed fingers. In most cases, all gymnasts, regardless of gender, exhibited lower values for CoP sway area, CoP displacement, and CoP velocity, particularly when comparing the handstand with joined and fully stretched fingers to the handstand with wide open and flexed fingers.

However, it's worth considering that pressure is defined as force per unit area exerted in a direction perpendicular to the support surface. The progressively increasing maximum pressure values observed in the order mentioned could be attributed to the smaller support area in the handstand with wide open and flexed fingers compared to the other hand placements.

Additionally, it's possible that younger gymnasts, who lack experience with hand placement variations during handstands, may not have the necessary strength to effectively manage CoP sway with open and fully stretched or even further open and flexed fingers. Alternatively, an opposing hypothesis suggests that gymnasts with greater strength capabilities may be more inclined to perform corrective movements during a handstand with their fingers open and fully stretched, or even further apart and flexed, which could result in larger deviations in their CoP (Hedbávný et al., 2018). However, it's important to note that these hypotheses cannot be confirmed in the present research since the gymnasts' strength was not assessed or considered.

Additional support for these findings can be found in the hand area of support, which was larger for both hands during the handstand with joined and fully stretched fingers, followed by the handstand with open and fully stretched fingers, and the handstand with wide open and flexed fingers.

In the case of the handstand with joined and fully stretched fingers, the joint fingers may offer more stable support due to their contact with a solid surface. Additionally, in this hand placement, the palm-to-finger lever arm is longer compared to the other two variations. This longer lever arm allows for better sensitivity in both applying force at the fingertips and sensing changes in weight distribution at the palms and fingers, providing enhanced support, particularly in the anterior-posterior plane.

It is also possible that some gymnasts do not sufficiently align their shoulders over the wrists, which can affect their ability to effectively utilize the action of their fingers. Furthermore, it's important to note that the current study did not explore whether gymnasts had practiced and mastered a particular hand placement technique for executing the handstand.

Researchers reviewing the literature concerning the influence of anthropometric characteristics in balance performance reported conflicting results (Baker, Newstead, Mossberg, & Nicodemus, 1998; Kejonen, 2002; Odenrick & Sandstedt, 1984; Peterson et al., 2006), but they used different methods and systems, therefore any comparison of results should be made with caution (Kejonen, 2002). Training experience is another factor that could affect balance performance. Several studies confirmed the significant impact of professional gymnastic training on body stability in natural and unnatural balance positions (Gautier, Marin, Leroy, & Thouvarecq, 2009; Hedbávný et al., 2013; Kochanowicz et al., 2018). The results of the present study showed no differences between male and female gymnasts regarding age, body mass, height, BMI, and training age. However, although not statistically significant, there were some differences between male and female gymnasts. For example, females were older and had higher training age compared to males. To account for any potential effects of these variables on the gymnasts' performance during the handstand, as explained in detail below, it was decided to include these variables as covariates in the statistical analyses of the study.

Based on previous research evidence (Baker, et al., 1998; Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998), it could be hypothesized that the stability of the body during handstand in both directions is dependent on the width of the hand placement, while stability in the sagittal plane is additionally influenced by the hand surface area. In the present study, after controlling for the effects of age and personal characteristics of the gymnasts, there were significant differences between the two genders regarding hand placement area. Specifically, male gymnasts had a bigger area of each hand support in all cases, except for the hand area of the left hand during the handstand with wide open and fully stretched fingers. Considering these differences and based on the results of previous research (Baker, et al., 1998; Winter, et al., 1998), it could be expected that male gymnasts have better control and regulation of balance during the handstand. However, statistical analysis that controlled for age, personal characteristics, and hand support area did not reveal any differences in maximal pressure between genders. This lack of difference in force, which is directly related to the gymnasts' weight, and surface area may explain the absence of gender-based variations in maximal pressure.

In terms of maximal pressure, although statistical significance was not observed, it's noteworthy that in all cases, for both genders, the maximal pressure of the right hand was higher compared to the corresponding pressure on the left hand. These findings align with previous studies, which have indicated that both more and less experienced gymnasts tend to place more load on their right hand than on their left hand during handstand maintenance.

This suggests the predominant role of the right hand in bearing the main load, as the ground reaction force, during a handstand, regardless of the gymnast's level of experience (Sobera et al., 2019).

The results of the applied MANCOVAs showed that female gymnasts exhibited lower values in the CoP sway area during handstands with open and flexed fingers, as well as handstands with open and fully stretched fingers. They also had lower CoP linear distance displacement values in all cases, which included handstands with wide open and flexed fingers, handstands with open and fully stretched fingers, and handstands with joined and fully stretched fingers, when compared to males. Additionally, females demonstrated lower CoP velocity values, although this was significant only for handstands with joined and fully stretched fingers.

It's widely accepted by many researchers that less motion is positively correlated with better control over sways, resulting in smaller CoM displacements during handstands (Asseman et al., 2005; Hrysomallis, 2011). Taking these findings into account, the results of the present study provide evidence that female gymnasts exhibited superior balance performance in handstands compared to their male counterparts. This aligns with the findings of several previous studies (Eguchi & Takada, 2014; Smith et al., 2012; Steindl et al., 2006) that reported better balance performance in young females when compared to males of the same age.

Considering the age of the gymnasts who participated in the present study and research findings (Hirabayashi & Iwasaki, 1995; Steindl et al., 2006) which confirm that adolescents compared to children demonstrate better balance performances, it could be assumed that the different rate of maturation of parameters affecting balance control between the two genders could be a contributing factor to the variability in maintaining handstand. For example, maturation of the neurological, visual, vestibular, and proprioceptive systems appears to occur earlier in young females (Cratty, 1970). Thus, the better females' performance in handstand compared to males could be attributed to parameters such as improved sensory integration (Steindl et al., 2006), advanced neuromuscular development (Eguchi & Takada, 2014), and the use of more adult-like postural control strategies (Smith et al., 2012). Additionally, it has been suggested that compared to females, males tend to exhibit higher levels of hyperactivity (Hirabayashi & Iwasaki, 1995) and lower attentiveness during balancing skills, which could potentially have a negative impact on the visual, vestibular, and proprioceptive systems crucial for postural stability (Steindl et al., 2006). In summary, considering the possible differences in maturation between genders, it could be argued that the observed differences in balance control in the present research, where they were statistically significant, might be limited or even non-existent.

Another crucial factor believed to play a significant role in maintaining a handstand is the mobility and stability of the shoulder joint, particularly its relationship to upper body mechanics. During handstand execution, the shoulder joint is positioned almost at 180° (Rohleder & Vogt, 2018). Therefore, the active range of motion in the shoulders, especially in terms of flexion to open the shoulder angle, becomes a critical factor contributing to handstand control (Rohleder & Vogt, 2018; Uzunov, 2008).

As a result, gymnasts' ability to effortlessly straighten their shoulders plays a vital role in their capacity to maintain balance during handstands since the shoulder joints significantly influence the shifting of the center of mass (CoM) (Kerwin & Trewartha, 2001; Yeadon & Trewartha, 2003). When a gymnast lacks adequate active mobility in the shoulder joint, combined with potentially limited expertise, they may end up engaging not only the wrist joint (acting as a single-segment inverted pendulum) but also the hip joint (forming a double-segment inverted pendulum), leading to larger angular displacements (Blenkinsop et al., 2017; Gautier et al., 2009).

Taking these considerations into account, it's plausible to hypothesize that the gender differences in balance control during handstands observed in the present study could be attributed, at least in part, to variations in shoulder active mobility. Numerous studies have indeed reported that females tend to exhibit a higher range of motion in shoulder flexion compared to males (Armstrong, 2018; Gómez-Ladero, López-Bedoya, Vernetta, 2013).

Nevertheless, the current study did not uncover significant differences between male and female gymnasts in all the variables affecting handstand control that were examined. In contrast, prior research has shown that females and males exhibit similar levels of balance performance (Butz et al., 2015; Libardoni et al., 2017). Therefore, it remains uncertain whether and to what extent gender-related differences in young gymnasts' handstand performance are present.

However, due to the limitations of the present study, any generalization of these findings should be approached with caution. Specifically, aside from the small sample size of participants and the age range, this study did not assess certain gymnast characteristics, such as biological maturation, passive and active flexibility, and strength of shoulder flexion and wrist flexion and extension. Furthermore, performing the handstand on a posturographic platform with specific dimensions may have added difficulty for some gymnasts in controlling their balance, as they were required to place their hands within a narrower range than they were accustomed to. Additionally, this study did not consider the technical aspects of gymnasts' handstand performance, including the compensatory movement strategies employed to maintain balance. The inclusion of complementary kinematic methods in future studies could enhance the interpretative possibilities of the findings.

Future studies might evaluate handstand performance using different force plates, involve larger sample sizes with narrower age and training differences, consider factors such as gymnasts' biological and technical developmental stage, assess passive and active flexibility and strength in shoulder flexion and wrist flexion and extension, analyze technical characteristics of handstand performance using kinematic analysis or expert judges, explore longer handstand trial durations (e.g., >20 or 30 seconds), or determine the maximum time each gymnast can maintain a handstand, and investigate the relationships between different strategies for maintaining a handstand on the floor and on other apparatus, as well as their impact on overall gymnastics performance. Such studies may yield more consistent and applicable results that can be generalized.

CONCLUSIONS

This study examined the effects of different hand placement techniques employed during handstands on balance control, taking gender variance into account.

Regarding hand placement, both genders effectively control their balance during handstands with joined and fully stretched fingers, followed by handstands with open and fully stretched fingers, and finally handstands with wide-open and flexed fingers. After controlling for age, training experience, and personal characteristics, female gymnasts demonstrated superior balance control during handstands.

Considering the study's limitations, coaches are advised to initially teach the handstand without emphasizing specific hand placement (especially regarding palms and fingers). Instead, they should prioritize developing young gymnasts' specific flexibility and strength, including passive and active flexibility of shoulder and wrist flexion and extension, as well as body position and control. As gymnasts progress and gain experience, coaches can gradually introduce hand placement techniques, starting with flat palms and wide-open fingers and eventually progressing to open and flexed fingers. Additionally, taking gender into account when practicing or evaluating handstands in gymnastics is advisable.

In summary, while acknowledging the limitations of this study, its reliable findings contribute to the existing body of literature on balance control techniques during handstands, with a specific focus on gender differences. However, it's essential to recognize that these are preliminary findings that require further in-depth examination in the future, considering the recommendations outlined in the research limitations section.

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