

INVESTIGATION IN TERMS OF SOME VARIABLES OF THE POSITIONAL CORRELATION OF THE STRAIGHT-ARM PRESS HANDSTAND MOVEMENT IN ARTISTIC GYMNASTS

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Abstract

The objective of this study was to investigate in terms of some variables the positional correlation of the press to handstand with eyes open and eyes closed in the right-left sagittal planes in artistic gymnasts. Correlation analysis was conducted to evaluate the data. According to the findings obtained from analysis in the right and left planes at 0°, a statistically significant correlation was observed both in the negative and positive direction. The analysis of the gymnasts' press to handstand with eyes open and eyes closed, as measured in the right and left planes at 90°, revealed a statistically significant correlation both in the negative and positive direction. Likewise, the analysis of the gymnasts' press to handstand with eyes open and eyes closed, as measured in the right and left planes at 180°, revealed a statistically significant correlation both in the negative and positive direction. We found in our study that the wider the triangle formed by the gymnasts' shoulders, hips, and feet in the starting position of the press to handstand with eyes open was indicative of a poor starting technique, that at 90° the gymnasts' proprioception functioned differently in the right and left planes when performing a handstand with eyes open and eyes closed, and that at 180° the central nervous system may play an important role for the arm muscles in the right plane in maintaining the desired balance in the absence of visual input when performing the handstand with eyes closed.

Keywords: handstand, gymnastic, plane, position, proprioception.

INTRODUCTION

Gymnastics is a multidisciplinary sports branch that encompasses a wide array of performance variables, requiring a combination of speed, strength, endurance, flexibility, agility, and psychological traits such as courage and quick decision-making

(Şentürk & Sezen, 1999; Çoknaz, Yıldırım & Özengin, 2008). Artistic gymnastics, in particular, places a significant emphasis on intensive use of the upper extremities, as gymnasts strive to execute acrobatic

movements seamlessly and fluidly (Pala & Avcı, 2016).

Postural balance is paramount for success in artistic gymnastics, especially during sequences of moves. Gymnasts undergo drills to enhance and refine their movement skills, particularly for maneuvers requiring precise postural control, such as the handstand (Şimşek & Ertan, 2011). The handstand, characterized by supporting the body in a stable, inverted vertical position on the hands (Wyatt, Vicinanza, Newell, Irwin, & Williams, 2021), is a fundamental technique in artistic gymnastics. Improper execution of the handstand can expose gymnasts to various risks, including injury and failure to meet performance expectations in training sessions or competitions. Achieving the correct angles and coordinates in a handstand offers numerous advantages to gymnasts, enabling them to execute moves with proper technique and reducing the risk of injury. Multiple joints (wrist, shoulder, arm, head, leg-ankle, hip joints) and muscles (trapezius, biceps/triceps brachii, deltoid, rectus femoris, etc.) play crucial roles in maintaining balance and coordinating positioning during handstands.

An essential factor that helps gymnasts maintaining their desired handstand position is the sense of proprioception, which integrates visual, auditory, neural, and muscular cues. Proprioception involves the body's ability to sense its position and movement in space, updating visual and vestibular signals during motion. Mechanoreceptors in tendons, muscles, and ligaments play a crucial role in this process (Riemann & Lephart, 2002; Kaynak, Altun, Özer & Akseki, 2015). While mechanoreceptors interpret signals from

visual sensors to consciously maintain balance during a handstand, visual sensors may have a more specific role in unconscious reactions during movement, suggesting the importance of visual processes in achieving and sustaining balance. Proprioception engages both unconscious and conscious reactions to motion (Yılmaz & Gök, 2006). Therefore, our study aimed to investigate how performing the handstand with eyes open and eyes closed affects gymnasts' motion mechanism.

We believe that understanding the positional correlation of the press to handstand, one of the fundamental movements in artistic gymnastics, is crucial for a successful sports career. Our study seeks to contribute valuable insights into teaching proper positioning for the handstand.

METHODS

We conducted extensive research using search engines such as NCBI (including Pubmed and Pubmed Central), Researchgate, Google Scholar, and Web of Science, which are registered in internet databases, to inform our study. During these searches, we evaluated data obtained by using keywords such as "artistic gymnastics," "gymnastics and handstand," "handstand and balance," and "proprioception and balance in gymnastics." We used them to supplement our study findings.

The inclusion and exclusion criteria for the research group are provided in Table 1, Demographic data of the research group are provided in Table 2.

Table 1

Criteria for athlete participation in the study: inclusion and exclusion

Inclusion criteria	Exclusion criteria
Being under 18 years old	Being an artistic gymnastics athlete
Being Turkish Citizen	Being able to communicate in Turkish
Being a male and female athlete	Have parental consent forms
Not having any disability	Being an elite athlete
Not having any disease that can affect the balance	Being an international athlete
Not having an infectious disease	Being an international and national level competitor

Table 2

Demographic data of the participating gymnasts (n=20).

Variables	Mean	SD
Age (years)	16.85	2.28
Height (cm)	1.64	9.73
Weight (kg)	57.57	9.49
BMI (kg/m ²)	21.21	1.85
Sports years (years)	10.85	2.41
Daily training hours (hours)	4.52	1.12
Warm-up time (minutes)	34.76	8.72

SD: Standard deviation

The study included 16 male and 5 female gymnasts, all members of the Murat Canbas Training Centre in Bolu, with prior experience in national and international competitions. Participation in the study was voluntary, and athletes did not inhibit their involvement. Written parental consent was obtained for participants under the age of 18.

Given that the participating athletes are also engaged in educational activities, our tests were designed not to disrupt their academic programs. Additionally, precautions were taken to assess whether athletes exhibited any symptoms of illness, including those related to seasonal conditions and the COVID-19 virus.

Table 2 represents the anthropometric measurements of the gymnasts, including age, height, weight, and BMI, were recorded at least twice by the tester, and the mean

values were documented on personal information forms.

The height of the athletes in our study was measured with a Holtain brand device that was made with a height \pm sensitivity of 1mm. Weight measurements were taken with the Xiaomi Mi Body Composition Scale 2 Model, which has a precision of \pm 50 g. Body mass index (BMI) values were calculated by dividing the weight by the square of height.

Upon examining the demographic information of the athletes in the artistic gymnastics branch:

- It was observed that the gymnasts had a sports history of over ten years.
- They trained for an average of four hours per day, with training sessions starting with warm-up exercises lasting at least half an hour.

To assess the force exerted by gymnasts during the straight-arm press to handstand, the arm force utilized to shift the load from lower extremities to shoulders, abdomen, scapula, and back muscles through core strength was measured using a Lafayette dynamometer. This measurement was conducted with the gymnasts seated on a flat surface. Prior to measurement, gymnasts performed specialized warm-up exercises targeting the shoulders, abdomen, scapula, and back muscles.

Subsequently, the dynamometer was positioned on the distal arm section of the gymnasts, who were then instructed to exert maximal force by pushing the dynamometer both backward and forward. Each

measurement was repeated at least twice (once for the right and once for the left arm), and the mean value was recorded on the information form by the tester.

The gymnasts' press to handstand with eyes open and closed was analyzed in the right-left planes at three different phases of the handstand: 0° , 90° , and 180° . Two GoPro cameras, capable of 5.3K60/2.7K240 Video and 27MP Photos, were positioned on each side, right and left, at a distance of 3 meters each. Prior to camera measurements, the area designated for the gymnasts' movements was prepared by the tester to ensure proper positioning for camera measurements, as seen on Figure 1.



Figure 1. Exemplary illustration of the calibration frame and camera angle

To assess the gymnasts' movements in a coordinate plane (X, Y), a rectangular calibration frame was established using 1.30 m high slalom poles, defining a 2 m long and 1 m wide area. Green markers were applied to specific anatomical landmarks on the gymnasts' lateral side of the hand, wrist joints, the lateral proximal end of the ulna, the greater tubercle of the humerus, the

lateral and lower parts of the latissimus dorsi, the greater trochanter of the femur, the lateral part of the knee joint, and the articular cavities of the ankles.

The gymnasts performed the press to handstand with their eyes open or closed in a randomized order. Upon reaching the handstand position, they were instructed to maintain it for at least 5 seconds. Gymnasts

who failed to execute the press to handstand satisfactorily on their first attempt were given two additional attempts.

After the handstand, the video recordings were analyzed with Kinovea motion analysis software. Two researchers simultaneously paused the videos at predetermined positions for each phase of the motion in two directions and inserted markers.

During marking, the x-y coordinates of the gymnasts' right and left feet were determined in the triangle (0°), feet parallel to the ground (90°), and handstand (180°) positions on the software's coordinate system. Additionally, the coordinates of the height of the feet from the ground, the triangle, and shoulder angles were determined and included in the analysis.

Coordinate, force, and inertial data were integrated into two-dimensional dynamic analyses. Each gymnast was depicted with four segment models: hand, arm, trunk-head, and leg sections. Corresponding joints for these sections were identified as wrist, shoulder, and hip.

Equations of motion were developed for each of the four segments, with three equations assigned to each segment, resulting in a total of twelve equations. Within each of the three joints, six equations were left, which could be resolved to eliminate reactions. These reactions were denoted as T_1 , T_2 , T_3 , and ϕ_1 , ϕ_2 , and ϕ_3 (Yeadon & Trewartha, 2003) (Figure 2).

The kinematics of handstand balancing, particularly the angle positions of the joints, the center of mass, and the torques due to the force of gravity, are illustrated. Active engagement of the joints and muscles during a handstand can significantly aid athletes in achieving the desired balance. Kerwin and Trewartha (2001) concluded in their study that multiple joints actively contribute to maintaining handstand balance in the anterior-posterior direction. During a handstand, which demands effective production of relative force, athletes must counteract the torque generated by the force of gravity with their body weight.

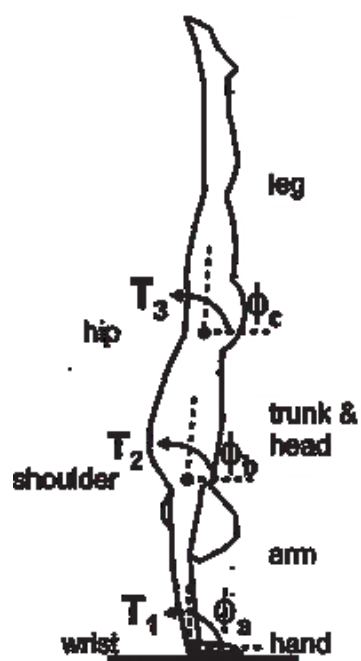


Figure 2. Demonstration of the four segment model in the handstand movement.

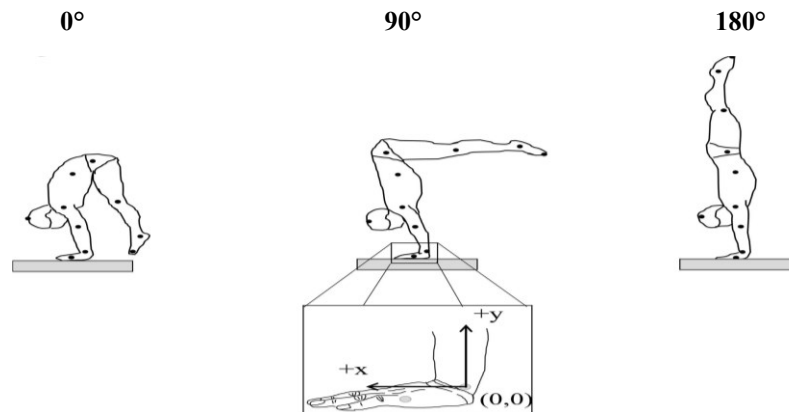


Figure 3. Straight-arm press to handstand measurement positions

The press to handstand position for measurement was standardized for the straight-arm press to handstand (Figure 3). With the assistance of expert coaches from the national team, athletes executed the straight arm press handstand movement on a force surface. Prior to measuring the handstand movement, athletes were instructed to maintain tension in their wrist, elbow, shoulder, hip, knee, and ankle joints throughout the duration of the measurement.

During the movement, athletes positioned their wrist joints to form a 90-degree angle over the x and y axes. Furthermore, athletes were cautioned against stepping forward or backward during the handstand movement to maintain control of pressure and optimize force utilization, especially considering the effect of gravity while in the inverted position.

In this study, the angular positions of the handstand movement performed with eyes open and closed in the sagittal plane were evaluated. The statistical analysis of the data obtained utilized the correlation analysis method, commonly employed to ascertain the direction and strength of relationships between variables. The data were uploaded to the SPSS 22.0 software package for analysis, and the results were

interpreted. The statistical significance level for our study data was set at $p < 0.05$.

RESULTS AND DISCUSSION

The data obtained from the study are presented in Table 3, Table 4, Figure 4 and Figure 5. When examining the correlation between locations on the coordinate plane and isometric force values of the gymnasts' body segments at the starting position (0°) with eyes open, in terms of right plane coordinate data, a moderate and negative correlation ($r = -0.455$) was observed between right arm posterior isometric force values and feet X ($p < 0.05$). According to left plane coordinate data, a negative correlation was observed between right arm posterior isometric force values and the location of shoulder angle ($r = -0.453$) and feet X ($r = -0.195$), and a positive correlation was observed with the triangle ($r = 0.532$). In addition, a negative correlation was observed between left arm anterior isometric force values and the location of shoulder angle ($r = -0.354$) and shoulder Y ($r = -0.576$) ($p < 0.05$). A positive correlation was observed between left arm posterior isometric force values and the triangle ($p < 0.05$). According to both coordinate data obtained from the right plane ($r = 0.487$) and

coordinate data from the left plane ($r = 0.496$), a correlation was observed between shoulder angle and shoulder Y ($p < 0.05$). Regarding both planes, statistically significant correlations were observed

between right and left shoulder angle ($r = 0.615$), triangle ($r = 0.760$), feet Y ($r = 0.868$), hip Y ($r = 0.863$), shoulder X ($r = 0.654$), and shoulder Y ($r = 0.811$) ($p < 0.05$).

Table 3.

Isometric strength values of participations.

Variable	Mean	SD
R.A.A.I. (kg)	6.570	1.910
R.A.P.I. (kg)	6.619	1.987
L.A.A.I. (kg)	6.857	2.032
L.A.P.I. (kg)	7.380	1.990

Abbreviations: **R.A.A.I:** Right Arm Anterior Isometric, **R.A.P.I:** Right Arm Posterior Isometric, **L.A.A.I:** Left Arm Anterior Isometric, **L.A.P.I:** Left Arm Posterior Isometric, **SD:** Standart Deviation

$P < 0,05$

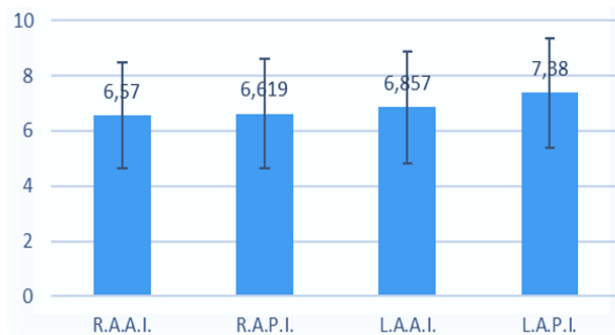


Figure 4. Isometric strength graph of gymnastics (The data in the graph are given in kg)

Table 4

Coordinate values according to participants' position with eyes open and eyes closed.

Variable	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed
H.F.G.	-	-	73.04 ± 12.40	73.33 ± 10.28	178.50 ± 11.39	179.34 ± 10.82
H.S.A.	133.12 ± 8.97	135.12 ± 11.27	145.45 ± 10.95	145.41 ± 12.05	159.01 ± 9.00	159.66 ± 9.33
H.S.T.	70.15 ± 12.73	66.86 ± 10.16	91.08 ± 1.95	90.73 ± .80	170.92 ± 7.48	172.02 ± 5.06
F.X.C.	109.90 ± 27.74	105.39 ± 22.36	44.86 ± 15.60	45.07 ± 15.78	41.33 ± 9.51	41.52 ± 10.12
F.Y.C.	113.02 ± 10.94	105.97 ± 24.99	117.30 ± 24.81	116.04 ± 32.47	61.56 ± 15.14	64.90 ± 12.18
H.X.C.	47.33 ± 5.68	44.49 ± 10.86	35.60 ± 6.32	45.20 ± 42.98	30.05 ± 7.24	30.46 ± 6.27
H.Y.C.	81.01 ± 12.64	80.63 ± 10.49	57.21 ± 5.73	56.97 ± 6.67	68.11 ± 5.64	67.66 ± 6.96
S.X.C.	79.01 ± 4.98	77.92 ± 7.18	78.83 ± 9.92	79.21 ± 8.75	77.15 ± 4.76	77.50 ± 5.43
S.Y.C.	56.37 ± 9.52	56.40 ± 7.29	52.00 ± 8.90	51.68 ± 8.79	66.93 ± 5.53	65.72 ± 7.69

Abbreviations: **H.F.G:** Height of Feet from Ground, **H.S.A:** Handstand Shoulder Angle, **H.S.T:** Handstand Shoulder Triangle, **F.X.C:** Feet X Coordinate, **F.Y.C:** Feet Y Coordinate, **H.X.C:** Hip X Coordinate, **H.Y.C:** Hip Y Coordinate, **S.X.C:** Shoulder X Coordinate, **S.Y.C:** Shoulder Y Coordinate, **Mean ± sd.** = Mean ± standard deviation

P<0,05

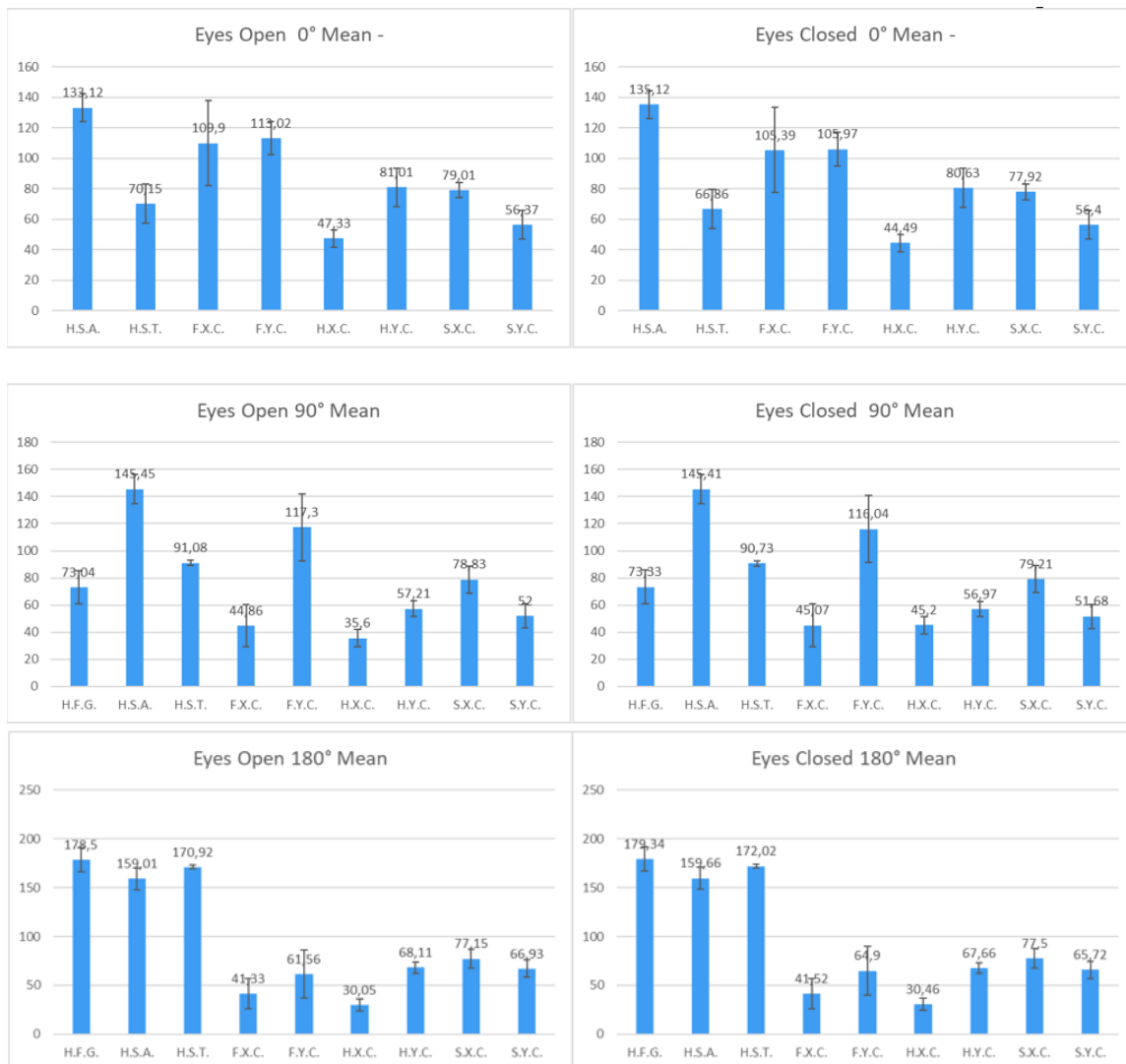


Figure 5. Coordinate position graph of gymnastics

At the starting position (0°) with eyes closed, according to the right plane coordinate data, a moderate and negative correlation was observed between left arm anterior isometric force values and shoulder angle ($r = -0.548$), as well as between right arm posterior isometric force values and shoulder Y ($r = -0.469$). In the left plane coordinate data, a negative correlation was found between left arm posterior isometric force values and feet X ($r = -0.615$) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left shoulder angle ($r =$

0.833), triangle ($r = 0.848$), feet Y ($r = 0.756$), feet X ($r = 0.484$), hip Y ($r = 0.913$), and shoulder Y ($r = 0.863$) ($p < 0.05$).

At 90° with eyes open, in the right plane coordinate data, a moderate correlation was noted between right arm posterior isometric force values and feet Y ($r = 0.497$) and shoulder Y ($r = -0.455$). A moderate and negative correlation was observed between left arm posterior isometric force values and shoulder angle ($r = -0.455$). In the left plane coordinate data, statistically significant correlations were found between right arm anterior isometric force values and shoulder

angle ($r = -0.595$) and shoulder Y ($r = -0.513$), between right arm posterior isometric force values and feet Y ($r = 0.585$) and shoulder Y ($r = -0.581$), between left arm anterior isometric force values and shoulder angle ($r = -0.552$) and shoulder Y ($r = -0.537$), and between left arm posterior isometric force values and shoulder angle ($r = -0.546$) and feet Y ($r = 0.562$) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of feet from the ground ($r = 0.976$), feet X ($r = 0.676$), feet Y ($r = 0.683$), hip X ($r = 0.469$), hip Y ($r = 0.774$), and shoulder Y ($r = 0.880$) ($p < 0.05$).

At 90° with eyes closed, according to the right plane coordinate data, a moderate and negative correlation was observed between right arm anterior isometric force values and shoulder Y ($r = -0.462$). Additionally, a moderate correlation was noted between right arm posterior isometric force values and feet Y ($r = 0.554$) as well as shoulder Y ($r = -0.521$). Furthermore, a moderate and negative correlation was seen between left arm posterior isometric force values and shoulder angle ($r = -0.461$) and shoulder Y ($r = -0.515$). In the left plane coordinate data, statistically significant correlations were observed between right arm anterior isometric force values and shoulder angle ($r = -0.609$), as well as between right arm posterior isometric force values and shoulder angle ($r = -0.567$), feet Y ($r = 0.497$), and shoulder Y ($r = -0.576$) ($p < 0.05$). Similarly, statistically significant correlations were seen between left arm anterior isometric force values and shoulder angle ($r = -0.608$), and between left arm posterior isometric force values and shoulder angle ($r = -0.664$) and shoulder Y ($r = -0.523$) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of

feet from ground ($r = 0.952$), shoulder angle ($r = 0.582$), feet X ($r = 0.779$), feet Y ($r = 0.677$), hip Y ($r = 0.808$), and shoulder Y ($r = 0.815$) ($p < 0.05$).

At 180° with eyes open, according to the right plane coordinate data, a moderate and positive correlation was observed between right arm posterior isometric force values and height of feet from ground ($r = 0.501$) and feet X ($r = 0.543$), while the correlation with hip X ($r = -0.636$) was moderate and negative. Additionally, a moderate and negative correlation was found between left arm anterior isometric force values and shoulder Y ($r = -0.505$), as well as between left arm posterior isometric force values and shoulder Y ($r = -0.464$). In the left plane coordinate data, a moderate and positive correlation was observed between right arm posterior isometric force value and height of feet from ground ($r = 0.502$). Across both planes, statistically significant correlations were seen between right and left height of feet from ground ($r = 0.976$), feet X ($r = 0.758$), feet Y ($r = 0.635$), hip Y ($r = 0.741$), and shoulder Y ($r = 0.642$) ($p < 0.05$).

At 180° with eyes closed, according to the right plane coordinate data, a moderate and significant correlation was observed between right arm anterior isometric force values and shoulder angle ($r = -0.445$), as well as between right arm posterior isometric force values and height of feet from ground ($r = 0.492$), shoulder angle ($r = -0.514$), and hip X ($r = -0.558$) ($p < 0.05$). Additionally, a moderate and significant correlation was seen between left arm anterior isometric force values and shoulder angle ($r = -0.453$), and between left arm posterior isometric force values and shoulder angle ($r = -0.578$) and triangle ($r = 0.527$) ($p < 0.05$). In the left plane coordinate data, a moderate and positive correlation was observed between right arm posterior

isometric force values and height of feet from ground ($r = 0.514$) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of feet from ground ($r = 0.967$), shoulder angle ($r = 0.678$), feet X ($r = 0.810$), feet Y ($r = 0.636$), hip Y ($r = 0.795$), and shoulder Y ($r = 0.815$) ($p < 0.05$).

Our study revealed contrasting findings regarding the relationship between right-left isometric arm muscle force at 0° and coordinate values such as shoulder angle, feet X, and shoulder Y. While there was an increase in right-left isometric arm muscle force at 0° , there was a decrease in coordinate values related to shoulder angle, feet X, and shoulder Y. Additionally, we observed that with an increase in right arm posterior isometric arm muscle force in the left plane with eyes open, the angles of the triangle formed by shoulders, hip, and arms widened, resulting in poorer handstand performance. This phenomenon suggests that gymnasts may shift their body mass center and body pressure center to their posterior right arm during the press to handstand. Notably, this was not observed in the starting position (0°) of the press to handstand with eyes closed.

We found that in the starting position with eyes closed, gymnasts utilized their left arm posterior isometric muscle force in the left plane and their left arm anterior isometric muscle force in the right plane. These results imply that gymnasts may utilize their arm force at 0° more balanced and economical manner when their eyes are closed. Furthermore, our findings suggest that gymnasts develop different proprioception strategies under changing conditions (eyes open/closed) to master the starting position of the press to handstand.

To further explore this phenomenon, Heinen, Jeraj, Vinken, & Velentzas (2012) conducted a study on rotational preferences in gymnastics, revealing that gymnasts develop individual rotational preferences and talent practices. This finding aligns with our study's results, suggesting that gymnasts develop movement-specific strategies to coordinate body mass centers differently at the beginning of force handstand movement, with eyes open and closed. Pryhoda, Newell, Wilson, & Irwin (2022) have determined that different balance control strategies are employed in handstand and standing postures.

The analysis conducted in the right and left planes at 90° with eyes open and eyes closed revealed statistically significant correlations, both in the negative and positive directions. Interestingly, we observed that contrary to the increase in anterior-posterior right-left isometric arm muscle force, there was a decrease in coordinate values dependent on shoulder angle and shoulder Y. Moreover, in conjunction with the increase in right and left arm isometric arm muscle force, there was an increase in coordinate values dependent on feet Y. This observation suggests a potential stimulation for forward motion of the head, back, and hips, as well as upward motion of the feet, aiming to achieve the desired handstand position while maintaining the current position of shoulder areas at 90° of the press to handstand movement.

To further explore this phenomenon, Grabowiecki, Rum, Laudani, & Vannozi (2021) conducted a study on the biomechanical characteristics of handstand walking initiation. They concluded that a successful handstand walking initiation required a shift of the center of mass forward and towards the stance hand, accompanied

by a lateral and posterior shift of the center of pressure. These findings align with the results of our study, suggesting a similar mechanism at play.

Our study revealed differences between the 90° handstand with eyes open and the 90° handstand with eyes closed. At 90° (i.e., the second phase of the press to handstand) with eyes open, gymnasts narrowed their shoulder angles in the right plane by utilizing right and left arm posterior isometric muscle force to achieve the desired movement position. Conversely, when performing the handstand with eyes closed, gymnasts employed their right arm posterior, right arm anterior, and left arm posterior isometric muscle force to adjust shoulder Y to the desired motion position, thus reaching the desired motion angle.

The high level of experience and elite status of the gymnasts in our study likely played a significant role in these findings. Similarly, Sobera, Serafin & Rutkowska-Kucharska (2019) concluded in their study that more experienced gymnasts concentrate on handstand movement by minimizing medial-lateral body swing and anterior-posterior body swings. Additionally, Omorczyk, Bujas, Puszczalowska-Lizis, & Biskup (2018) found that more experienced gymnasts performed better in both the handstand and standing positions compared to young athletes.

These observations regarding the 90° position of the press to handstand may stem from gymnasts' efforts to utilize their force more economically and employ techniques that are more suitable before advancing to 180°. In line with the data obtained from our study, it can be inferred that gymnasts execute specific muscle movements tailored to the position in their handstand movements performed at different angles. Accordingly, gymnasts may engage in specific muscle

activations tailored to varying conditions in the handstand position (Kochanowicz, Niespodziński, Mieszkowski, Marina, Kochanowicz & Zasada, 2019).

At 90° with eyes closed, it was observed that the absence of visual input prompted gymnasts to actively engage their right arm anterior muscle force in the right plane and their left arm posterior muscle force in the left plane, in addition to their anterior-posterior arm muscles that are actively used when performing the motion with eyes open. The gymnasts' proficiency in positioning their body parts at a correct angle at 90° of the press to handstand, whether with eyes open or closed, can serve as an important predictor of a successful handstand.

In a study conducted by Kochanowicz et al. (2016) on the biomechanical indicators of the forward handspring vault and maximal power of the lower limbs, it was found that the angles of the hip joint in the second phase of the flight and when the hands touched the vault surface might influence the received score. Additionally, athletes' ability to maintain their bodies in the correct position before the handstand at a 90° angle, whether with eyes open or closed, may involve other control systems.

In their study, Gautier, Thouvarecq & Chollet (2007) concluded that both the central-peripheral angle of view and other balance control systems may play a crucial role in the postural regulation of handstand movement.

In our study, the analysis conducted in the right and left planes at 180° with eyes open and eyes closed showed a statistically significant correlation both in the negative and positive direction. This might be attributed to gymnasts attempting to achieve the desired balance position in handstand by engaging various muscle groups, including the arm muscles, in the right-left planes, with

both eyes open and closed. In this regard, Kochanowicz, Niespodziński, Marina, Mieszkowski, Biskup, & Kochanowicz (2018) concluded in their study that several muscle groups actively contributed to maintaining balance in handstand. Additionally, postural weight can also play a crucial role in maintaining the desired balance in the right-left planes. Thomas et al. (2023) concluded in their study that postural weight played a significant role in handstands on the sagittal plane. The reflex developed by the neck may also be pivotal in gymnasts' ability to maintain balance stability in the 180° handstand position. During the handstand movement, the neck area can serve as an important guide for keeping the body in the correct position. For this purpose, Asseman and Gahéry's (2005) study found that the tonic neck reflex may play a significant role in maintaining gymnasts in the correct posture during handstands. The conclusions drawn in the aforementioned studies align with our study. However, our study identified some differences between handstands performed with eyes open and those performed with eyes closed. Specifically, our study revealed that gymnasts utilized their right arm posterior isometric arm muscle force on the right plane to maintain the desired balance in handstands with eyes open, whereas they employed their right arm posterior, right arm anterior, left arm anterior, and left arm posterior muscle force to maintain balance in handstands with eyes closed. Furthermore, our study observed that, in contrast to the increase in isometric arm muscle force with eyes closed, there was a decrease in shoulder angles and hip X levels. This phenomenon may occur because the central nervous system enhances its influence on the arm muscles to maintain the desired balance when visual input is absent during handstand

performance with eyes closed. Gymnasts may develop various strategies to sustain the desired balance at 180° with eyes closed by interpreting stimuli received by the central nervous system from the peripheral nervous system. Specifically, the feedback system comprising the brain, cerebellum, afferent (sensory), and efferent (motor) nerves likely plays a crucial role in shaping these strategies.

In the handstand, the static balance created by body mass centers and sudden changes in balance can trigger a sequence of muscular reactions, primarily dependent on the afferent nervous system and subsequently on central generators (Ergen, Ülkar & Eraslan, 2007). Additionally, apart from the neural strategies developed by gymnasts when performing handstands with eyes closed, the vestibular system, a fundamental component of proprioception, can also significantly contribute to balance in blindfolded handstands. This contribution may primarily involve controlling body weight. In support of this notion, a study conducted by Jessop and McFadyen (2008) concluded that the vestibular system stimulates an increase in body weight during the standing posture with one eye closed, facilitating the body to maintain balance. In addition to this finding from our study, factors such as executing the motion with proper technique, depending on individual differences, may also play a significant role. A study by Blenkinsop, Pain, and Hiley (2017) on balance control strategies in handstands revealed that while the central nervous system employed various control strategies during a handstand balance trial, these strategies were applied individually rather than simultaneously.

Moreover, in another study by Mizutori, Kashiwagi, Hakamada, Tachibana, & Funato (2021), it was observed that some

gymnasts generated larger shoulder flexion moments during handstands, whereas others exhibited larger hip flexion moments.

In our study, it was observed that the narrowing of the shoulder and hip angles (due to an increase in anterior-posterior isometric arm force) in the handstand with eyes closed exemplifies correct handstand technique. Considering that artistic gymnastics is a sport where champions are determined by subtle nuances, the angular positions of the shoulders and hips, influenced by gravity, can be crucial in teaching gymnasts the correct handstand skill (Koçak, 2019).

However, contrary to the conclusion reached in our study, Puszczalowska-Lizis and Omorczyk (2019) found in their research on body balance in standing position and handstands in gymnasts that disabling visual control during free standing, as well as adopting a handstand position, resulted in a deterioration of stability indices. This finding contrasts with the results of our study. Additionally, Isotalo, Kapoula, Feret, Gauchon, Zamfirescu, & Gagey (2004) concluded in their study that unilateral vision in postural control may provide stability equal to or even better than bilateral vision.

Despite the divergent results from these studies, artistic gymnastics remains a sport characterized by intensive training practices. Therefore, gymnasts should be exposed to higher workloads to attain the desired level of proficiency in movements requiring a fixed position such as the handstand (Malíř, Chrudimský, Štefl, & Stastny, 2023).

LIMITATIONS

- Evaluation of athletes within one single day due to their involvement in intense competition schedules.

- Some athletes exhibited agitated attitudes during handstand movement.
- Athletes experienced excessive balance losses during handstand movement.

Challenges arose in obtaining the necessary permits to work.

CONCLUSIONS

In this study, we conducted an in-depth analysis of the positional kinematics of the press to handstand, a fundamental movement in aesthetic sports such as artistic gymnastics, where elegance converges with power. Proper body positioning on the floor at the outset of the movement is crucial for gymnasts to execute the press to handstand accurately, efficiently, and with correct technique.

We concluded in our study that a wider triangle formed by the gymnasts' shoulders, hips, and feet in the starting position of the press to handstand with eyes open was indicative of poor starting technique. Additionally, we observed that at 90°, gymnasts' proprioception functioned differently in the right and left planes when performing a handstand with eyes open and eyes closed, leading to variations in angle usage and differences in the utilization of right-left isometric arm muscle force.

Furthermore, we found that gymnasts utilized their right-left isometric arm muscle force and adjusted their angular position in the right-left planes to maintain balance in the handstand at 180°, irrespective of whether their eyes were open or closed.

Our study revealed that gymnasts effectively utilized proprioception during the press to handstand, regardless of whether their eyes were open or closed. Additionally, we concluded that significant differences in angle positions during the press to handstand, attributed to variations in

proprioception and individual preferences, may arise due to discrepancies in isometric arm muscle force.

Gymnasts actively engage their muscles to maintain the correct position in the press to handstand, particularly when performing with their eyes closed. Based on the findings of our study, gymnastics coaches should incorporate blindfolded practices into their athletes' training regimens, especially focusing on handstand and related movements. This approach could positively contribute to both neuromuscular adaptation and proprioceptive awareness.

Moreover, by directing their attention solely on the movement, gymnasts can shield themselves from the detrimental effects of environmental stimuli.

ETHICAL STATEMENTS

Necessary permissions for conducting the study were obtained from the Turkish Ministry of Youth and Sports and the Turkish Gymnastics Federation. For our study, the necessary permissions were obtained from the Gazi University Ethics Commission with the number E-77082166-604.01.02-608841.

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