**Are the shoulder joint function, stability, and mobility tests predictive of handstand execution?**

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# Abstract

Handstand is a basic unstable element common across gymnastic disciplines that is frequently evaluated for quality in skill acquisition and competition. The execution of handstands relies on maintaining balance through corrective strategies, where the shoulders seems particularly important. This study explores the relationship between shoulder joint function and the quality of handstand execution in college athletes (n = 111). We assessed the stability and mobility of the shoulder joints using standardized and purpose-built field tests and quality was evaluated on two official rating scales. Ordinal logistic regression models showed no relationship between the quality of handstand execution and measures of shoulder joint stability and mobility in our sample. Two major factors may cause this pattern of results. Firstly, the standardized tests assess shoulder joints in different loads and ranges of motion compared to handstands, and also because our sample had limited ability to perform the handstand sufficiently well.

# Keywords: gymnastics; upper extremity; quality of movement; physical education; Y balance test, range of motion

# Introduction

Handstand is one of the basic and most prevalent elements in physical education and gymnastics. Apart from being a standard skill used to assess movement literacy (Tidén et al., 2015), the capability and proficiency of performing a handstand are crucial for learning more advanced and combined gymnastics elements, such as “handstand to forward roll”, “backwards roll to handstand” or handsprings (Kojima et al., 2021; Uzunov, 2008). These elements are commonly used in physical education (Kojima et al., 2021) and elementary, junior, and high school-level gymnastics. In artistic gymnastics, the handstand is a fundamental skill (Kerwin & Trewartha, 2001; Mizutori et al., 2021; Sobera et al., 2019; Uzunov, 2008) performed in several dynamic (i.e., parallel bar, pommel horse) and static (maintaining a balanced inverted body position, i.e. floor exercises, rings) forms. The static form of the handstand is of particular relevance as it is frequently the initial and/or the final position of many elements’ structures (Hedbávný et al., 2013; Kochanowicz et al., 2015).

The quality of handstand execution is important not only for skill acquisition but also in gymnastics performance evaluation. Generally, the reached quality of performance may range from ‘fail to perform given element or not recognisable’, execution with large errors, to performances ‘without any errors’. Such evaluation is important for athletes, gymnastics couches, PE teachers, and other experts responsible for and involved in training and competition performance outcomes. Qualitative scales with a different range of points are commonly used for such evaluations (Fink et al., 2021b; Kovač, 2012). The Assessment of the Quality Value (AQV) is one such scale used to evaluate the technical performance aspects of selected elements. The AQV evaluation ranges from 0 to 4 points, where 0 represents the worst (not accomplished) and 4 the best (no errors) (Fink et al., 2021b, 2021a). Compared to qualitative rating scales, the E-score is another assessment possibility (International Gymnastics Federation, 2017). The E-score assigns decimal point values (i.e., 0.1; 0.3; 0.5; 1.0) for errors made in a particular element (International Gymnastics Federation, 2017). It is a somewhat finer evaluation tool compared to AQV, already used to assess handstand execution in physical education classes by Kojima et al. (2021) (in concordance with MAG CoP (International Gymnastics Federation, 2017)).

In comparison to the natural (bipedal) stance, a handstand is an unstable balance position. It is specific by its greater distance of the center of mass (COM) from the ground, the smaller size of the support base, and differences in body segments’ position (Hedbávný et al., 2013; Kochanowicz et al., 2019), such as the lower position of the head in relation to the surface (Sobera et al., 2019). Another specificity of this position is the different structures of the upper extremities utilized in a handstand versus the lower extremities utilized in a natural stance (Sobera et al., 2019). All these aspects lead to higher demands to maintain stability (Sobera et al., 2019). The ability to perform a handstand and keep the balance is influenced by multiple factors, mainly by sensory control systems (visual, vestibular, and proprioceptive (Gautier et al., 2009; Krištofič et al., 2018; Shumway-Cook & Woollacott, 2012)), sport’s performance level and experience (Omorczyk et al., 2018). Maintaining the handstand is a complex process of reciprocal coordination of the wrists, elbows, shoulders, and hips. Multiple strategies are used to maintain a balanced position. In practice, these balance strategies are usually combined, mainly to maintain balance in the anterior-posterior direction. In the wrist strategy (Hedbávný et al., 2013; Kerwin & Trewartha, 2001; Kochanowicz et al., 2019), the primary goal is to balance a handstand with extended and fixed body segments by isometric muscle contraction (particularly using wrist torque) (Kerwin & Trewartha, 2001). The elbow strategy allows for corrective movements using elbow flexion to quickly lower the body’s COM to maintain balance (Slobounov & Newell, 1996). Finally, the hip strategy uses hip flexion to compensate for greater shifts in COM (Blenkinsop et al., 2017; Hedbávný et al., 2013; Kerwin & Trewartha, 2001; Yeadon & Trewartha, 2003). From the perspective of gymnastics performance evaluation, it seems that specific balance strategies resulting in a larger range of corrective movements will result in worse performance rating (e.g., a higher score deductions for the execution (Fink et al., 2021a)).

Gautier et al. (2009) argue that the coupling of wrists and shoulders is the key factor for balance control in handstand position among expert gymnasts, while less experienced gymnasts control their handstand position mainly using their hips. Other authors (Kochanowicz et al., 2019; Prassas et al., 1986; Yeadon & Trewartha, 2003) have also suggested that shoulders are an important joint group for maintaining balance during handstands, as the shoulder joints are influential in the center of mass (COM) shifting (Kerwin & Trewartha, 2001). Furthermore, the active range of motion (aROM) in the shoulder joints plays a significant role in cases where the handstand is the subsequent or final position of a given element’s structure into which athletes need to transfer. Prassas et al. (1986) claim that the power in the shoulder joint flexion is one of the prerequisites of executing a proper press handstand, where arms are in parallel position, and 180° degrees at shoulder joints are required (Rohleder & Vogt, 2018). Also, Uzunov (2008) discusses the need for shoulder joint flexion aROM to maintain approximately 180° during a handstand. The results of Kochanowicz et al. (2019) testing muscle activity during a handstand on various gymnastic apparatus using electromyography support this claim. The activity of the anterior deltoid muscle together with the rectus femoris while maintaining a handstand on parallel bars were essential contributors. Even greater demands are placed on the muscles controlling the shoulder joints (i.e., trapezius muscle, deltoid muscles, biceps brachii, latissimus dorsi) during handstand in rings (Kochanowicz et al., 2019). Currently, the shoulder strategy (using shoulders to compensate for a stable position) is another yet less recognized strategy for maintaining a handstand (Gautier et al., 2009; Kerwin & Trewartha, 2001).

Shoulder joint function can be divided into two capacities, mobility and stability (Veeger & van der Helm, 2007), which are often assessed in many sports (Beyranvand et al., 2017; Borsa et al., 2008; Hill et al., 2015; Nuhmani, 2022; Zarei et al., 2021). Multiple tests and procedures were developed for their evaluation. The Upper Quarter Y Balance Test (UQYBT) is frequently used to assess the mobility and functional stability of the body’s upper quarter (Gorman et al., 2012). This test has high test-retest reliability (0.80-0.99, Gorman et al., 2012) and has already been used in many sports areas, such as sports games (handball, volleyball, tennis) (Borms & Cools, 2018), gymnastics (Beyranvand et al., 2017), combat sports (Gottlieb et al., 2018) or weightlifting (Salo & Chaconas, 2017). In this test, athletes stabilise their body weight with the upper extremities while reaching maximum distance (by sliding movable cuboids) on three different axes: mediolateral, inferolateral, and superolateral (Westrick et al., 2012). Another commonly used test to assess shoulder joint stability across multiple sports areas such as sports games (baseball, basketball, volleyball, football) (Declève et al., 2021; Hollstadt et al., 2020; Pontillo & Sennett, 2020; Roush et al., 2007) and gymnastics (Pontillo & Sennett, 2020) is the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST). The CKCUEST is a reliable (0.68-0.87, De Oliveira et al., 2017) test in which the performance is measured by counting the number of times (during a 15-second period) athletes can touch their supporting hand with the other while maintaining a push-up position (Goldbeck & Davies, 2000; Tucci et al., 2014). Joints range of motion (ROM) and aROM play an important role in shoulder joint function (Uzunov, 2008). In gymnastics, the shoulder joints’ aROM (mobility) is tested predominantly with specific field tests in open (OKC) or closed kinetic chain (CKC) (Fink et al., 2021a, 2021b; Mkaouer et al., 2018; Vernetta et al., 2020). A common feature of these tests is keeping the trunk straight with maximum flexion of both arms in specific body positions (Fink et al., 2021b, 2021a; Mkaouer et al., 2018) while the range of flexion is assessed.

It seems that the shoulder function and its relation to the upper body position of the play an important role in maintaining a handstand. However, there are no studies investigating the influence of shoulder joint functions and the quality of movement execution, such as handstands. Therefore, this study aims to examine the relationship between shoulder joint mobility and stability and the quality of handstand execution. To do so, the performances in field tests for shoulder joint stability (CKCUEST), stability in combination with mobility (UQYBT), and mobility test (aROM) were compared with scores from expert judgments of execution (based on FIG, CoP 2017-2020) and the five-grade qualitative assessment scale (Fink et al., 2021a, 2021b). We predict that participants with better quality handstand execution will also have higher scores in shoulder joint stability and mobility tests.

# Materials and Methods

Data from this study are part of a larger project investigating the associations between the function and stability of the shoulder joint and the handstand execution quality.

The study took part during the winter and summer terms in 2020 and was conducted in the sports gym of the Faculty of Physical Education and Sport of Charles University. All procedures were carried out in accordance with the Declaration of Helsinki and under relevant safety rules regarding the COVID-19 pandemic. The Institutional Review Board of the Faculty of Physical Education and Sport of Charles University approved the study (198/2020). All participants were informed about the study goals and signed informed consent before participation.

## Participants

We recruited 111 first-year bachelor’s degree students (35 women and 76 men) from the Faculty of Physical Education and Sport at Charles University from Physical Education and Sport and Coaching study programmes. All participants were athletes of various sports backgrounds (the sports background of each participant is available in the Supplemental digital content of this article). Sample descriptives are reported in Table 1 (descriptives for each sex are available in the Supplemental digital content). Only participants with no history of shoulder surgeries or acute upper limb injury were allowed to participate.

Table 1 – Sample descriptive statistics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Mean** | **SD** | **Min** | **Max** |  |  |
| Age (years) | 20.21 | 1.02 | 19 | 23 |  |  |
| Height (cm) | 175.73 | 9.37 | 152.1 | 202 |  |  |
| Weight (kg) | 71.83 | 10.09 | 43.5 | 91.8 |  |  |
| UQYBT Right | 86.06 | 5.77 | 70.2 | 100 |  |  |
| UQYBT Left | 85.51 | 5.66 | 73.4 | 100.8 |  |  |
| UQYBT Total | 85.78 | 5.4 | 71.8 | 100.4 |  |  |
| CKCUEST | 27.84 | 3.77 | 15.67 | 39.33 |  |  |
| E-score | 1.62 (2.0\*) | 0.54 (0.65\*\*) | 0.1 | 2.2 |  |  |
|  |  |  |  |  |  |  |
| Variable | **Mode** | **Rating** | | | | |
| **0** | **1** | **2** | **3** | **4** |
| AQV | 1.13 | 21 | 67 | 15 | 4 | 4 |
| SPT | 1,2 | - | 52 | 52 | 7 | - |

Note: \* mode; \*\* interquartile range; higher AQV and SPT mean better score, higher E-score means more deduction and worse score, higher UQYBT and CKCUEST tests results mean better performance.

## Data collection

### Procedures

Data collection took place at the end of the winter and summer terms when all participants had completed the Basic gymnastics course. All participants underwent two 45minute lessons focused on static handstands performed on the floor during the course. All participants took part in this study during the last lesson of the course. The approximately 20 (±5) participants were divided into six groups. Three groups of participants were tested at the end of the winter term and three at the end of the summer term.

The testing was carried out in the same fashion for all groups. Participants were familiarized with the course of the study and all testing procedures. Subsequently, participants obtained a protocol form that included an assigned ID and contained fields to fill in the results of all testing procedures; each participant carried the protocol form throughout the testing period (see in the Supplemental digital content). They filled in their sport specialisation, age, and arm and leg laterality (not analyzed in this study). Next, all participants underwent anthropometric measurements of body height, weight, and arm’s length (not analyzed in this study). Arm length was measured in the upright standing position with arms abducted to 90°. The lengths of both arms were measured from the C7 vertebra spinous process to the dactylion (of the longest finger as per (Cook, 2010). Subsequently, the participants performed a standardized and supervized (by AP and RM) 8-minute warm-up (mobilisation and stretching) predominantly focused on the upper body and shoulder joints, including typical gymnastic warm-up exercises.

After the warm-up, each group of participants out of six mentioned above was broken down into four subgroups of approximately 4-6 participants. The subgroups were randomly assigned to stations with the given test (1. Station – handstand evaluation; 2. Station – Upper Quarter Y Balance Test; 3. Station – Closed Kinetic Chain Upper Extremity Stability Test; 4. Station – Sit Position Test). There were two research assistants at each station. The subgroups always continued to the next station with a fixed resting period of 5 minutes before the start of the test at the given station. After finishing all the testing, the participants handed in the filled-in protocols.

### Station 1 - Handstand execution, recording, and evaluation

Each participant started from the middle of a firm 5 cm thick mat (200×100 cm). A soft 10 cm thick mat (200 ×100 cm) was placed in front of the firm mat as a safety precaution in case of a fall from the handstand position. There was approximately a 40 cm wide gap between the two mats where participants were to put their hands during handstand execution (Figure 1). The participant was instructed to perform a handstand and keep the balance for 2 seconds without additional movements. Each participant had the option to choose a starting position from two predefined and execute the handstand directly from this position. The predefined positions were 1) starting from a front support position with hands put on the ground and one leg bent 2) starting from a standing position with arms up dynamically transferring into directly putting hands in the gap. The research assistant gave verbal instructions “start” to start and “stop” to finish the handstand attempt. Each participant had a maximum of three attempts to perform the handstand. The first successful attempt was recorded.



Figure 1 – Handstand execution station (side view showing the gap between the mats and the hands placement).

Two digital cameras were used to record the execution of the handstands of every participant. The first (front view) camera (DSLR Canon EOS 550D equipped with Canon Zoom Lens EF-S 18-135mm 1:3.5-5.6 IS set to its widest setting, recording in 1080p, 30fps) in landscape orientation was placed on a tripod approximately 1 metre above the floor and 6 metres in front of the participant. The second (side view) camera (Canon HF-R17 with Lens 3.0-60.0mm 1:1.8 set to its widest setting, recording 1080p and 25fps) was also placed on a tripod approximately one metre above the floor and 5 meters away from the right side of the participant during handstand execution. The recording of each participant included the starting position and the successful attempt; all body segments were always visible during the handstand, except for the ankles and feet, which were irrelevant for later evaluation.

The quality of handstands was evaluated with two methods. First, we used the qualitative 5-point scale, the *Assessment of the Quality Value* (AQV) by Fink & Hofmann (2021a & 2021b). The scale ranges from 0 (*not accomplished)* to 4 (*very good technique and execution, no errors)* points defined by the *Fédértion Internationale Gymnastique* (FIG) (Fink et al., 2021a, 2021b). As the second method, we assessed the quality of the handstand using the E-score evaluation of the *execution and technical performance aspects* according to MAG CoP (International Gymnastics Federation, 2017). This evaluation addspoints and their fractions starting at 0 points for flawless execution and technique. For any deviation of the angle in the hips, knees, shoulders, and elbows from the correct position, up to 0.5 points were added (0.1 error points = up to 15°; 0.3 error points = 16° - 30°; 0.5 error points = more than 30°). The addition of 0.3 points was accounted for when participants kept their legs apart during the handstand position. When participants were unable to hold the position for the full 2 seconds, 0.3 points were added, and 0.5 error points if there was no holding of the position during execution. When a participant fell from the handstand (uncontrolled descent from the handstand position), 1 point was added.

Three members of the authors’ collective (RM, JCh, AP), each with more than ten years of practical experience in artistic gymnastics, independently assessed each participant’s performance of a handstand by observation of the recorded frontal and side view on both assessing scales (AQV and E-score).

### Station 2 – The Upper Quarter Y Balance Test

The shoulder joint stability was measured using two standardized field tests: Upper Quarter Y Balance Test (UQYBT) (Gorman et al., 2012) and the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) (Tucci et al., 2014). For the UQYBT, we used the standardized procedure for the Y balance test kit (Cook, 2010). The testing position was a single arm push-up with legs a pelvic width apart, keeping a straight body position. The hand of the support arm was positioned next to the red line markings on the middle block of the test kit (Gorman et al., 2012). Participants were instructed to use their free hand to move sliding blocks along three axes (mediolateral, inferolateral, and superolateral) as far as possible. Bending the elbow of the support arm, disrupting the prescribed body position, or touching the ground with a free hand was not allowed. Each participant had three attempts for each arm, with the right arm first tested (failed attempts were not counted). We set the breaks between attempts to 1 minute. Following the UQYBT protocol (Cook, 2010), we computed the score for the right and left arms separately as a sum of the furthest reaches (cm) in all three axes divided by the corresponding arm length times three and then multiplied by 100:

UQYBT Right

Note: formula example for UQYBT Right; med = mediolateral directions; inf = inferolateral direction; sup = superolateral direction

We recorded the UQYBT score for the right arm (UQYBT Right), left arm (UQYBT Left) and the total score (UQYBT Total). The UQYBT Total score was obtained as a mean of UQYBT Right and UQYBT Left. Only the UQYBT Total score was used for subsequent analyses.

### Station 3 – The Closed Kinetic Chain Upper Extremity Stability Test

The CKCUEST test was performed in a wide push-up position with hands 1 yard (91.5 cm) apart with a straight body position and legs a pelvic width apart (De Oliveira et al., 2017). From this position, participants were instructed to lean over one hand (supported hand), touch the dorsum of the supported hand with the free hand, return the free hand to starting position, and repeat the task with the other hand. The main goal of this task is to perform hand touches as fast as possible, regardless of which limb starts. Each participant had three 15 second attempts (Tucci et al., 2014) with 1-minute breaks between attempts (failed attempts were not counted). Each participant began and finished the test withverbal cues “start” and “stop” from the research assistant. For the CKCUEST score, we calculated the mean number of hand touches for all three trials of the CKCUEST (Tucci et al., 2014) and used it for the subsequent data analysis.

### Station 4 – Active range of motion test

To estimate the shoulder joint active range of motion (aROM) in flexion, we used a proprietary field test, the Sit-position test (SPT). The participants were seated on an approximately 30 cm high fitness box next to the wall with legs kept at approximately 90° angle in the knees, a pelvic width apart, and whole feet on the ground. The upper body position was set to a straight trunk with straight arms pulled into an overhead position keeping the shoulder width apart without bending the elbows and wrists. Participants were to keep their heads in a neutral position with the trunk extended while looking forward. They kept this position for 5 seconds (Figure 2). One side view camera (Casio EX-ZR10 with 5.0-35.0mm 1:3.0-5.9 zoom lens, placed approximately 5 metres from the left side of each participant, recording in 1080p, zoom set to its widest setting) was used for the recording of the entire SPT test duration. If the participant’s test position was interrupted for any reason, the participant was prompted to repeat the test procedure. A member of the authors’ collective (AP) evaluated the aROM SPT test of the shoulder joint flexion (relative position of the arms, head, and trunk) from video recordings using Kinovea® 0.8.19 (Charmant, 2004). The aROM SPT Test execution was rated as 1 = bad (arms in front of the trunk line); 2 = passing (arms in line with the trunk line); 3 = good (arms behind the trunk line).

The descriptive statistics of all participants’ performances and assessments are shown in Table 1.



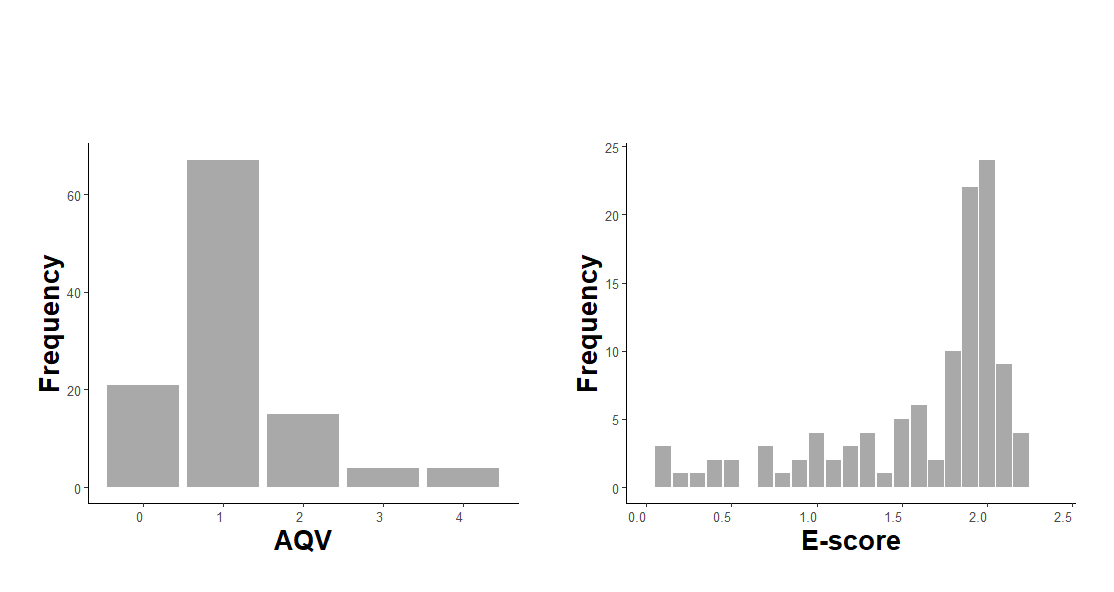
Figure 2 – Sit-position test (SPT) for aROM in flexion of the shoulder joints.

## Data processing and statistical analysis

All data were entered into MS Excel 2016 spreadsheets, subsequently processed and analyzed using R version 4.2.1 (R Core Team, 2022) via RStudio IDE (RStudio Team, 2022).

### Concordance between evaluators

Kendall’s coefficient of concordance from the *rcompanion* package (Mangiafico, 2022) was used to assess the concordance between three AQV and E-score evaluators. We selected W ≥ 0.7 (p ≤ 0.05) as a sufficient level of concordance. The final AQV score was based on the mode of the assigned ratings of all three evaluators, and for the final E-score, we used the mean score. Figure 3 highlights the frequency of reached AQV and E-score scores.

Figure 3 – Frequencies of reached AQV (left plot) and E-score (right plot) scores.

### Exploratory data analysis

We assessed the normality distribution of all continuous variables (UQYBT Right, UQYBT Left, UQYBT Total, CKCUEST & E-score) using Shapiro-Wilk test. Next, we assessed the equality of variance between all continuous variables included for data analysis (UQYBT Total, CKCUEST, E-score) by Fligner-Killeen’s test using *fligner.test* function from *stats* package (R Core Team, 2022).

We treat the AQV and SPT scores as ordinal variables; thus, we did not perform normality tests and variance equality tests for them and used non-parametric tests for their subsequent analyses.

Using the *cor.test* function from *stats* package (R Core Team, 2022), we explored associations (and possible collinearities) between variables. We performed correlation analyses using Pearson’s r with its 95% CI (for parametrically distributed variables, i.e., UQYBT Right and UQYBT Left, UQYBT Total and CKCUEST) and Kendall’s τ with its 95% CI (for non-parametrically distributed variables, i.e., SPT and UQYBT Total, SPT and CKCUEST; we used *kendall.ci* function from *NSM3* package (Schneider et al., 2022) for CI estimates). The threshold of close association and interchangeability was set to ≥ 0.7. If the association between a pair of variables reached this predefined value, we used only one of them.

Further, we used Kendall’s rank correlation to assess the association between AQV and E-scores. We expected a negative association between AQV and E-score because the better the execution of the handstand, the higher the score in AQV is, but a lower score in E-score should be achieved. In this case, we chose a value of τ ≥ -0.7 as a close association and interchangeability.

### Relationship between quality of handstand and shoulder stability and mobility tests

We used a regression model to test the relationship between handstand execution quality and shoulder stability and mobility tests. Variance inflation factor (VIF) in *car* package (Fox et al., 2022) was used to assess the assumption of multicollinearity between predictors (i.e., UQYBT Total, CKCUEST and SPT) with a predefined level of multicollinearity < 5.0 (Akinwande et al., 2015). If the VIF criterion is greater than the predefined value, we will remove highly correlated predictors from the models (Akinwande et al., 2015) to avoid increasing standard errors estimates of coefficients (Akinwande et al., 2015; Miles, 2014).

We set up two ordinal logistic regression models to analyse the relationship between the quality of handstand execution (AQV and E-score) and the results of the stability, functionality, and mobility of the shoulder joint tests (UQYBT Total, CKCUEST, SPT). Due to the ordinal scaling of the AQV and E-score, we fitted an ordinal logistic regression (*formulas*: AQV ~ UQYBT Total + CKCUEST + SPT and E-score ~ UQYBT Total + CKCUEST + SPT) using *MASS* package (Ripley et al., 2022). We used *performance* package (Lüdecke et al., 2022) for RMcFadden2 and RMcFadden adj.2 computations. Anova function from *car* package (Fox et al., 2022) was used for the computation of χ2 for all three predictors. Subsequently, we used Brant’s test to assess parallel regression assumption (PRA) within the ordinal logistic regression model using *brant* package (Schlegel & Steenbergen, 2022) with a predefined alpha level for PRA of p ≥ 0.05. The main output of the ordinal logistic regression is reported as proportional odds ratios (POR) for individual coefficients of the model (independent variables) and their 95% CI.

### SUPPLEMENTAL ONLINE MATERIAL

The dataset file (in .xlsx), commented R script with outputs of detailed results of all performed analyses, and supplementary data analyses are available in the Supplemental digital content of this article.

# Results

### Concordance between evaluators

The results of Kendall’s coefficient of concordance showed sufficient agreement between the three judges for both the AQV scale (W = 0.75 [0.749, 0.780], p < 0.001) and the E-score (W = 0.79 [0.761, 0.984], p < 0.001). Therefore, we used mean values of the E-score and mode values of AQV for each participant.

### Data assumptions and exploratory data analysis

According to the results of the Shapiro-Wilk test, all continuous variables met the assumption of normal distribution (all Ws ≥ 99, ps ≤ 0.94), except the E-score (W = 0.81, p < 0.001), where the normality assumption was not met. The homogeneity of variance assumption was met between all sets of variables (i.e., UQYBT Total and E-score; CKCUEST and E-score).

Results of UQYBT Right and UQYBT Left were highly and statistically significantly correlated (r111 = 0.78 [0.70, 0.84], p < 0.001). We found a weak negative and statistically non-significant correlation between UQYBT Total and CKCUEST (r111 = -0.05 [-0.24, 0.14], p = 0.583), also between SPT and UQYBT Total (τ111 = -0.15 [-0.27, -0.03], p = 0.053) and weak statistically non-significant positive between SPT and CKCUEST (τ111 = 0.06 [-0.06, 0.17], p = 0.46). The AQV and E-score were statistically significantly and strongly negatively associated, as expected, but the strength of correlation was lower than our predefined threshold value (τ111 = -0.68 [-0.772, -0.581], p < 0.001).

The results of VIF criterion analysis regarding the multicollinearity of predictors for each subsequent regression model suggest no multicollinearity (UQYBT Total = 1.08; CKCUEST = 1.01; SPT = 1.08).

For detailed results of all the analyses mentioned above, see the supplemental online material.

### Relationship between quality of handstand and stability and mobility tests

Overall, our ordinal logistic regression model for AQV reached RMcFadden2 = 0.012 (RMcFadden adj.2 = 0.004) with residual deviances 247.79 (dfResidual = 104). None of our three measures predicted the observed AQV scores statistically significantly or with substantial odds (Table 2, Figure 4). The proportional odds ratio (POR) shows that for every one-unit (1 cm) increase in the UQYBT Total, the odds of being better in the AQV increase on average by only 6%. Every unit increase in the CKCUEST (one more touch) equals to a 1% decrease in the odds of being better in the AQV on average. The SPT indicates the comparatively highest POR. For every one-unit increase in the SPT, the odds of being better in the AQV increase on average by 43%. However, in all instances, the lower limits of 95% CI were below 1 (e.g., 0.76 – a decrease of 24% in the case of SPT).

The Brant’s test of the first model (with AQV as dependent variable) showed that the PRA holds for all variables, including Omnibus (UQYBT Total, CKCUEST, SPT and Omnibus) with ꭓ2 ≥ 0.03; p ≥ 0.16, and therefore the model holds PRA.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Predictor** | **Coefficient (β)** | **Std. Error** | **t value** | **p** | **POR** | **95% CI (LL, UL)** | **χ2 (p)** |
| UQYBT Total | 0.05 | 0.04 | 1.48 | 0.14 | 1.06 | 0.98, 1.14 | 2.20 (0.14) |
| CKCUEST | -0.01 | 0.05 | -0.3 | 0.77 | 0.99 | 0.89, 1.09 | 0.09 (0.77) |
| SPT | 0.36 | 0.33 | 1.1 | 0.27 | 1.43 | 0.76, 2.74 | 1.22 (0.27) |

Table 2 – Summary of model estimates for UQYBT Total, CKCUEST, and SPT for AQV score.

The second ordinal logistic regression model for E-score reached RMcFadden2 = 0.003 (RMcFadden adj.2 = -0.001) with residual deviances 565.33 (dfResidual = 88). As with our first model with AQV, none of our three measures predicted the observed E-score as statistically significant or with substantial odds (Table 3, Figure 4). The POR shows that for every 1 cm increase in the UQYBT Total, the odds of being better in the E-score decreased on average by 3%. Within the CKCUEST, every additional touch increased leads on average to 0% change in odds of being better in the E-score; in other words: in our sample, the CKCUEST does not influence E-score. For every one-unit increase in the SPT, the odds of being better in the E-score decrease on average by 16%. As with the previous model, in all instances, the 95% CI LL were below 1.

The Brant’s test of the second model (E-score as dependent variable) holds PRA for UQYBT Total (ꭓ2 = 17.50, p = 0.56), CKCUEST (ꭓ2 = 22.75, p = 0.25) and Omnibus (ꭓ2 = 69.83, p = 0.12). Brant’s test did not hold the PRA for SPT (ꭓ2 = 36.43, p = 0.01) within the ordinal regression model.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Predictor** | **Coefficient (β)** | **Std. Error** | **t value** | **p** | **POR** | **95% CI (LL, UL)** | **χ2 (p)** |
| UQYBT Total | -0.03 | 0.03 | -1.01 | 0.32 | 0.97 | 0.91, 1.03 | 1.02 (0.31) |
| CKCUEST | 0 | 0.05 | -0.01 | 0.99 | 1 | 0.91, 1.09 | 0.00 (0.99) |
| SPT | 0.14 | 0.31 | 0.5 | 0.62 | 1.16 | 0.64, 2.07 | 0.24 (0.62) |

Table 3 – Summary of model estimates for UQYBT Total, CKCUEST and SPT for E-score.

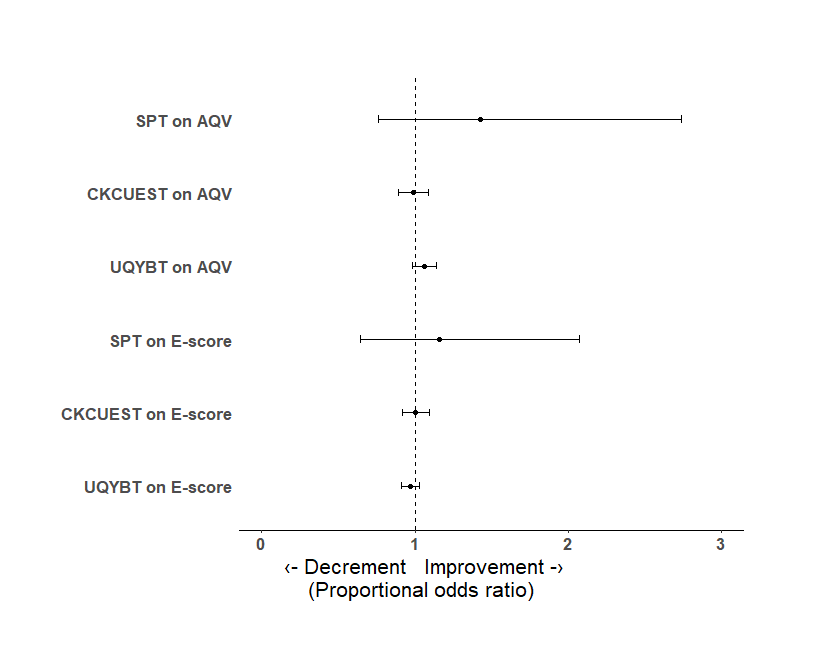


Figure 4 – Proportional odds ratios of shoulder joint function measures and AQV and E-score.

Note: Black dots represent observed effect sizes and error bars 95% CIs. The dashed vertical line represents no change in odds. Values below 1 are decrements in odds, and above 1 are improvements in odds.

# Discussion

Multiple strategies of compensating COM shifts to better hold handstand position have previously been discussed in the literature (Gautier et al., 2009; Hedbávný et al., 2013; Kerwin & Trewartha, 2001; Sobera et al., 2019; Yeadon & Trewartha, 2003). However, they were mostly omitting the role of shoulders, while multiple authors argued and provided supportive evidence for shoulder joint function (e.g. aROM or shoulder muscles strength) (Gautier et al., 2009; Kochanowicz et al., 2019; Prassas et al., 1986; Pryhoda et al., 2021; Uzunov, 2008) being an important element for handstand execution. Therefore, the aim of this study was to investigate the relationship between the quality of handstand execution and shoulder joint function and stability assessed using standardized (UQYBT & CKCUEST) and unstandardized (SPT) field tests in a sample of physically active athletes. Based on our analyses, we observed that the results of both standardized and unstandardized field tests of shoulder joint functioning have no significant effect on either AQV or E-score rating and, thus, on the quality of handstand execution.

We selected two particular rating scales, the standard qualitative AQV scale (AQV; Fink et al., 2021a, 2021b) and the E-score by MAG CoP (International Gymnastics Federation, 2017), to assess the handstands execution. According to our expectations and obtained results, the AQV and E-score are closely negatively associated; those who received a bad rating in AQV (lower score) also received a bad rating in E-score (higher value). However, based on the observed level of association, AQV and E-score should not be considered interchangeable and both provide different insight into the performed exercise quality.

Two standardized field tests (UQYBT & CKCUEST) were used to assess shoulder joint stability and complex function. Although other studies (with smaller samples) report a moderate positive correlation between UQYBT and CKCUEST(e.g., r30 = 0.49; Westrick et al., 2012), our results (r111 = -0.05) are more in accordance with Taylor et al. (2016) (r257 range = 0.04-0.18), showing virtually no relationship between these two tests, supporting the claim that both tests measure different aspects of shoulder function (Taylor et al., 2016).

The shoulder joint position is nearly 180° during handstand execution (Rohleder & Vogt, 2018). Thus, the level of shoulders’ aROM should be an important factor contributing to maintaining a handstand. We used a purpose-devised sit position test (SPT) to evaluate aROM in shoulder joint flexion with three levels. Unlike the handstand itself, in this mobility test, the shoulder joint is not loaded with the performer’s weight. This can be seen as a considerable factor affecting our results. This issue can also be raised against other field tests of shoulder joint mobility used here (UQYBT & CKCUEST loading shoulders in different axes compared to handstand) and in gymnastics in general (i.e., in Fink et al., 2021b, 2021a; Mkaouer et al., 2018; Vernetta et al., 2020). However, Wattanaprakornkul et al. (2011) claim that similar muscle activity patterns are produced during flexion torque regardless of the load (Wattanaprakornkul et al., 2011). Thus, the position and load during the test should not substantially affect the observed patterns of results.

Gorman et al. (2012) state that there is a required level of shoulder mobility to perform UQYBT (Gorman et al., 2012). Although we observed the association between the UQYBT and SPT as statistically non-significant, it has a negative slope (τ111 = -0.15 [-0.27, -0.03], p = 0.053). This pattern of the result may suggest, in accordance with Gorman et al. (2012), that participants with worse aROM in shoulder joint flexion also tend to show lower UQYBT Total scores. The greater aROM of the shoulder joint may allow reaching a greater distance in all directions in UQYBT Total (i.e., mediolateral, inferolateral and superolateral). However, greater aROM does not necessarily mean better shoulder joint stability. The accuracy of this needs verifying in future research as our study was limited by the distribution of observed SPT scores in our sample and the coarseness of the scale we used in the SPT assessment.

We observed only negligible changes in the odds of being better in the AQV and E-score depending on the UQYBT and CKCUEST. This indicates that the UQYBT and CKCUEST are not necessarily helpful tools for predicting the handstand execution, as suggested by the shoulder joint balance strategy. Although the UQYBT and CKCUEST tests are commonly used and were performed in compliance with respective protocols and in a standardized fashion, the explanation for the negligible odds could be the different positions of the upper extremities. Compared to when the upper extremities are in full flexion (approximately 180°) during handstand execution (Rohleder & Vogt, 2018), they are in the middle flexion (approximately 90°) during UQYBT and CKCUEST execution. The change in the odds of being better in the AQV with the increase in the SPT, though non-significant, may still suggest the role of an aROM in flexion and should be further investigated in future studies. As we mentioned above, the mobility in flexion of the shoulder joint may play an important role (Uzunov, 2008; Yeadon & Trewartha, 2003; Zivcic Markovic, 2015) as a lack of mobility could restrict the position with an “open shoulder angle” during handstand execution (Uzunov, 2008),.

A considerable limitation of our study is the imbalanceof the quality of handstand execution in our sample. The level of experience plays a role in the successful handstand execution (Omorczyk et al., 2018), but more than 60% (N = 67 of 111) of the sample reached an AQV score of 1 (*Intended element barely recognisable; Poor technical performance, incorrect body position (posture) or fall)* or failed to reach and hold the handstand altogether. This substantially skewed the observed data distribution, not allowing for better estimates of shoulder function on handstand execution. We can only conclude that handstand execution is a difficult skill for athletes of non-gymnastics backgrounds (e.g., a sample of physical education students from a wide range of different sports backgrounds). Further, though the CKCUEST is a standardized test with relatively high reliability, De Oliveira et al. (2017) point out the CKCUEST as a discordant test due to systematic error and significant differences during measurements. In addition, during the test, all athletes are instructed to keep their hands at the same distance (36 inches/1 yard/91.5 cm) regardless of maturational or anthropometric characteristics such as shoulder width or arm span, which may systematically affect the results (Taylor et al., 2016). Therefore, future studies should therefore extend and validate our findings using samples including more individuals capable of performing handstand and other shoulder function diagnostic tests.

To conclude, we observed no association between the shoulder joint function and the quality of handstand execution based on our data. Apart from the potential no *true* effect of the particular shoulder joint functions on handstand execution, these results could be explained by insufficient variability in the handstand capabilities of our sample and different shoulder joint positions during the UQYBT and the CKCUEST compared to those during a handstand. Somewhat worth further investigation remains the relation of SPT with the quality of handstand execution, with the tentative role of the aROM in flexion of the shoulder joint. Future research should aim to test the relationship between stability and mobility of the shoulder joint and the quality of handstand execution among gymnasts rather than a heterogeneous sample of physical education and sports students.

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The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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# References

Akinwande, M. O., Dikko, H. G., & Samson, A. (2015). Variance Inflation Factor: As a Condition for the Inclusion of Suppressor Variable(s) in Regression Analysis. *Open Journal of Statistics*, *05*(07), Art. 07. https://doi.org/10.4236/ojs.2015.57075

Beyranvand, R., Mirnasouri, R., Mollahoseini, S., & Mostofi, S. (2017). The functional stability of the upper limbs in healthy and rounded shoulder gymnasts. *Science of Gymnastics Journal*, *9*(3), 279–290. URN:NBN:SI:DOC-AQ3O8YVK from http://www.dlib.si

Blenkinsop, G. M., Pain, M. T. G., & Hiley, M. J. (2017). Balance control strategies during perturbed and unperturbed balance in standing and handstand. *Royal Society Open Science*, *4*(7), 161018. https://doi.org/10.1098/rsos.161018

Borms, D., & Cools, A. (2018). Upper-Extremity Functional Performance Tests: Reference Values for Overhead Athletes. *International Journal of Sports Medicine*, *39*(06), 433–441. https://doi.org/10.1055/a-0573-1388

Borsa, P. A., Laudner, K. G., & Sauers, E. L. (2008). Mobility and Stability Adaptations in the Shoulder of the Overhead Athlete. *Sports Medicine*, *38*(1), 17–36. https://doi.org/10.2165/00007256-200838010-00003

Cook, G. (2010). *Movement: Functional movement systems: screening, assessment, and corrective strategies*. On Target Publications.

De Oliveira, V. M. A., Pitangui, A. C. R., Nascimento, V. Y. S., da Silva, H. A., dos Passos, M. H. P., & de Araújo, R. C. (2017). Test-retest reliability of the closed kinetic chain upper extremity stability test (CKCUEST) in adolescents. *International Journal of Sports Physical Therapy*, *12*(1), 125–132. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5294939/

Declève, P., Van Cant, J., & Cools, A. M. (2021). Reliability of the Modified CKCUEST and correlation with shoulder strength in adolescent basketball and volleyball players. *Brazilian Journal of Physical Therapy*, *25*(5), 536–543. https://doi.org/10.1016/j.bjpt.2021.02.002

Fink, H., Hofmann, D., & Scholtz, D. (2021b). *Age Group Development and Competition Program for Men’s Artistic Gymnastics*. 123 pages.

Fink, H., López, L. O., & Hofmann, D. (2021a). *Age Group Development and Competition Program for Women’s Artistic Gymnastics*. 127 pages.

Fox, J., Weisberg, S., Price, B., Adler, D., Bates, D., Baud-Bovy, G., Bolker, B., Ellison, S., Firth, D., Friendly, M., Gorjanc, G., Graves, S., Heiberger, R., Krivitsky, P., Laboissiere, R., Maechler, M., Monette, G., Murdoch, D., Nilsson, H., … R-Core. (2022). *car: Companion to Applied Regression* (3.1-1). https://CRAN.R-project.org/package=car

Gautier, G., Marin, L., Leroy, D., & Thouvarecq, R. (2009). Dynamics of expertise level: Coordination in handstand. *Human Movement Science*, *28*(1), 129–140. https://doi.org/10.1016/j.humov.2008.05.003

Goldbeck, T. G., & Davies, G. J. (2000). Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test: A Clinical Field Test. *Journal of Sport Rehabilitation*, *9*(1), 35–45. https://doi.org/10.1123/jsr.9.1.35

Gorman, P. P., Butler, R. J., Plisky, P. J., & Kiesel, K. B. (2012). Upper Quarter Y Balance Test: Reliability and performance comparison between genders in active adults. *Journal of Strength and Conditioning Research*, *26*(11), 3043–3048. https://doi.org/10.1519/JSC.0b013e3182472fdb

Gottlieb, U., Kelman, D., & Springer, S. (2018). Evaluation of Two Simple Functional Tests to Predict Attrition from Combat Service in Female Light Infantry Soldiers. *Medical Science Monitor : International Medical Journal of Experimental and Clinical Research*, *24*, 9334–9341. https://doi.org/10.12659/MSM.911672

Hedbávný, P., Sklenaříková, J., Hupka, D., & Kalichová, M. (2013). Balancing in handstand on the floor. *Science of Gymnastics Journal*, *5*, 69–79.

Hill, L., Collins, M., & Posthumus, M. (2015). Risk factors for shoulder pain and injury in swimmers: A critical systematic review. *The Physician and Sportsmedicine*, *43*(4), 412–420. https://doi.org/10.1080/00913847.2015.1077097

Hollstadt, K., Boland, M., & Mulligan, I. (2020). Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) in a Modified Test Position in Division I Collegiate Basketball Players. *International Journal of Sports Physical Therapy*, *15*(2), 203–209. https://doi.org/10.26603/ijspt20200203

Charmant, J. (2004). *Kinovea* (0.8.19). https://www.kinovea.org/

International Gymnastics Federation. (2017). *2017 Code of points: Men’ ’s artistic gymnastics*. https://www.docdroid.net/dR5jZJ9/mag-cop-2017-2020-draft-1-pdf

Kerwin, D. g., & Trewartha, G. (2001). Strategies for maintaining a handstand in the anterior-posterior direction. / Strategies pour maintenir l ’ appui tendu renverse dans la direction antero-posterieure. *Medicine & Science in Sports & Exercise*, *33*(7), 1182–1188.

Kochanowicz, A., Kochanowicz, K., Niespodzinski, B., Mieszkowski, J., & Biskup, L. (2015). The level of body balance in a handstand and the effectiveness of sports training in gymnastics. *Baltic Journal of Health and Physical Activity*, *7*(4), 117–124. https://doi.org/10.29359/BJHPA.07.4.11

Kochanowicz, A., Niespodziński, B., Mieszkowski, J., Marina, M., Kochanowicz, K., & Zasada, M. (2019). Changes in the Muscle Activity of Gymnasts During a Handstand on Various Apparatus. *Journal of Strength and Conditioning Research*, *33*(6), 1609–1618. https://doi.org/10.1519/JSC.0000000000002124

Kojima, M., Kinomura, Y., & Kuzuhara, K. (2021). Development of observational indicators for evaluating handstand posture in the mat exercise in physical education class: Validity and reliability. *Journal of Physical Education and Sport*, *21*, 2087–2096. https://doi.org/10.7752/jpes.2021.s3266

Kovač, M. (2012). Assessment of Gymnastic Skills at Physical Education—The Case of Backward Roll. *Science of gymnastics journal*, *4*(3).

Lüdecke, D., Makowski, D., Ben-Shachar, M. S., Patil, I., Waggoner, P., Wiernik, B. M., Arel-Bundock, V., Thériault, R., Jullum, M., & gjo11. (2022). *performance: Assessment of Regression Models Performance* (0.10.0). https://CRAN.R-project.org/package=performance

Mangiafico, S. (2022). *\_rcompanion: Functions to Support Extension Education Program Evaluation\_. R package version 2.4.18* (R package version 2.4.18). https://CRAN.R-project.org/package=rcompanion

Miles, J. (2014). Tolerance and Variance Inflation Factor. In *Wiley StatsRef: Statistics Reference Online*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118445112.stat06593

Mizutori, H., Kashiwagi, Y., Hakamada, N., Tachibana, Y., & Funato, K. (2021). Kinematics and joints moments profile during straight arm press to handstand in male gymnasts. *PLOS ONE*, *16*(7), e0253951. https://doi.org/10.1371/journal.pone.0253951

Mkaouer, B., Hammoudi-Nassib, S., Amara, S., & Chaabène, H. (2018). Evaluating the physical and basic gymnastics skills assessment for talent identification in men’s artistic gymnastics proposed by the International Gymnastics. *Biology of Sport*, *35*(4), 383–392. https://doi.org/10.5114/biolsport.2018.78059

Nuhmani, S. (2022). Correlation between Core Stability and Upper-Extremity Performance in Male Collegiate Athletes. *Medicina*, *58*(8), Art. 8. https://doi.org/10.3390/medicina58080982

Omorczyk, J., Bujas, P., Puszczałowska-Lizis, E., & Biskup, L. (2018). Balance in handstand and postural stability in standing position in athletes practicing gymnastics [PDF]. *Acta of Bioengineering and Biomechanics; 02/2018; ISSN 1509-409X*. https://doi.org/10.5277/ABB-01110-2018-02

Pontillo, M., & Sennett, B. J. (2020). Profile of upper extremity strength and function in division 1 collegiate athletes. *Physical Therapy in Sport*, *44*, 8–13. https://doi.org/10.1016/j.ptsp.2020.03.003

Prassas, S. G., Kelley, D. L., & Pike, N. L. (1986). Shoulder joint torques and the straight arm/flexed hips press handstand on the parallel bars. *ISBS-Conference Proceedings Archive*.

Pryhoda, M., Newell, K., & Irwin, G. (2021). Handstand balance motor control mechanisms. *ISBS Proceedings Archive*, *39*(1), 212. https://commons.nmu.edu/isbs/vol39/iss1/55

R Core Team. (2022). *R: A language and environment for statistical computing.* https://www.R-project.org/.

Ripley, B., Venables, B., Bates, D. M., ca 1998), K. H. (partial port, ca 1998), A. G. (partial port, & Firth, D. (2022). *MASS: Support Functions and Datasets for Venables and Ripley’s MASS* (7.3-58.1). https://CRAN.R-project.org/package=MASS

Rohleder, J., & Vogt, T. (2018). Teaching novices the handstand: A practical approach of different sport-specific feedback concepts on movement learning. *Science of Gymnastics Journal*, *10*(1), 29–42. Scopus. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042864008&partnerID=40&md5=1c8f5f5abccfa3e4e374be1cdce6a6ce

Roush, J. R., Kitamura, J., & Waits, M. C. (2007). Reference Values for the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) for Collegiate Baseball Players. *North American Journal of Sports Physical Therapy : NAJSPT*, *2*(3), 159–163.

RStudio Team. (2022). *RStudio: Integrated Development Environment for R.* http://www.rstudio.com/

Salo, T. D., & Chaconas, E. (2017). The Effect of Fatigue on Upper Quarter Y-Balance Test Scores in Recreational Weightlifters: A Randomized Controlled Trial. *International Journal of Sports Physical Therapy*, *12*(2), 199–205.

Schlegel, B., & Steenbergen, M. (2022). *brant: Test for Parallel Regression Assumption*. 3. https://benjaminschlegel.ch/r/brant/

Schneider, G., Chicken, E., & Becvarik, R. (2022). *NSM3: Functions and Datasets to Accompany Hollander, Wolfe, and Chicken - Nonparametric Statistical Methods, Third Edition* (1.17). https://CRAN.R-project.org/package=NSM3

Slobounov, S. M., & Newell, K. M. (1996). Postural Dynamics in Upright and Inverted Stances. *Journal of Applied Biomechanics*, *12*(2), 185–196. https://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=20751616&site=ehost-live

Sobera, M., Serafin, R., & Rutkowska-Kucharska, A. (2019). Stabilometric profile of handstand technique in male gymnasts [PDF]. *Acta of Bioengineering and Biomechanics; 01/2019; ISSN 1509-409X*. https://doi.org/10.5277/ABB-01267-2018-02

Taylor, J. B., Wright, A. A., Smoliga, J. M., DePew, J. T., & Hegedus, E. J. (2016). Upper-Extremity Physical-Performance Tests in College Athletes. *Journal of Sport Rehabilitation*, *25*(2), 146–154. https://doi.org/10.1123/jsr.2014-0296

Tidén, A., Lundqvist, C., & Nyberg, M. (2015). Development and Initial Validation of the NyTid Test: A Movement Assessment Tool for Compulsory School Pupils. *Measurement in Physical Education and Exercise Science*, *19*(1), 34–43. https://doi.org/10.1080/1091367X.2014.975228

Tucci, H. T., Martins, J., Sposito, G. de C., Camarini, P. M. F., & de Oliveira, A. S. (2014). Closed Kinetic Chain Upper Extremity Stability test (CKCUES test): A reliability study in persons with and without shoulder impingement syndrome. *BMC musculoskeletal disorders*, *15*(1), 1–9. https://doi.org/10.1186/1471-2474-15-1

Uzunov, V. (2008). *The Handstand: A Four Stage Training Model*. https://doi.org/10.13140/RG.2.1.2985.1363

Veeger, H. E. J., & van der Helm, F. C. T. (2007). Shoulder function: The perfect compromise between mobility and stability. *Journal of Biomechanics*, *40*(10), 2119–2129. https://doi.org/10.1016/j.jbiomech.2006.10.016

Vernetta, M., Peláez-Barrios, E. M., & López-Bedoya, J. (2020). Systematic review of flexibility tests in gymnastics. *Journal of Human Sport and Exercise*, *17*(1). https://doi.org/10.14198/jhse.2022.171.07

Wattanaprakornkul, D., Halaki, M., Boettcher, C., Cathers, I., & Ginn, K. A. (2011). A comprehensive analysis of muscle recruitment patterns during shoulder flexion: An electromyographic study. *Clinical Anatomy*, *24*(5), 619–626. https://doi.org/10.1002/ca.21123

Westrick, R. B., Miller, J. M., Carow, S. D., & Gerber, J. P. (2012). Exploration of the Y-Balance Test for Assessment of Upper Quarter Closed Kinetic Chain Performance. *International Journal of Sports Physical Therapy*, *7*(2), 139–147. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3325634/

Yeadon, M. R., & Trewartha, G. (2003). Control Strategy for a Hand Balance. *Motor Control*, *7*(4), 421–442. https://doi.org/10.1123/mcj.7.4.421

Zarei, M., Eshghi, S., & Hosseinzadeh, M. (2021). The effect of a shoulder injury prevention programme on proprioception and dynamic stability of young volleyball players; a randomized controlled trial. *BMC Sports Science, Medicine and Rehabilitation*, *13*(1), 71. https://doi.org/10.1186/s13102-021-00300-5

Zivcic Markovic, K. (2015). A Suggested Model of Handstand Teaching Method. *Physical Culture*, *69*, 138–149.