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

Authors

Roman Malíř (ORCID id: 0000-0002-4668-3711)[1]*

Jan Chrudimský (ORCID id: 0000-0003-0026-1916)[1]

Adam Provazník (ORCID id: 0000-0002-9142-3468)[1]

Vít Třebický (ORCID id: 0000-0003-1440-1772)[1]

Affiliation

1 Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic

***Corresponding author**

Roman Malíř

malir@ftvs.cuni.cz

Department of Gymnastics and Combat Sports

Faculty of Physical Education and Sport, Charles University

José Martího 31

Prague 6, 162 52

Czech Republic

Abstract

Handstand is a basic element common across gymnastic disciplines and physical education classes that is frequently evaluated for quality in competition or skill acquisition. The correct handstand execution relies on maintaining balance, for which the shoulders seem particularly important. This study explores the relationship between shoulder joint function and the quality of handstand execution in novice college athletes (n = 111; aged 19 - 23 years). We assessed the shoulder joint function using standardized field tests (Upper Quarter Y Balance Test and Closed Kinetic Chain Upper Extremity Stability Test) and evaluated handstand execution on official rating scales.

Ordinal logistic regression models showed no relationship between the quality of handstand execution (AQV and E-score) and measures of shoulder joint stability or mobility in our sample (POR = 1.06 [0.98, 1.14] and 0.99 [0.89, 1.09] for AQV and POR = 0.97 [0.91, 1.03] and 1.00 [0.91, 1.09] for E-score).

Two major factors may have caused an observed pattern of results. Firstly, the standardized tests assess shoulder joint in different loads and ranges of motion compared to handstands, secondly, our novice sample were not able to perform the handstand sufficiently well. In our sample of novice college athletes, shoulder function seems not related to handstand execution as other latent factors hindered their performance.

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

Introduction

Handstand is an essential and frequent element in gymnastics and physical education (PE). It is a fundamental skill [1–4] performed both in dynamic (performed as position passing through swing exercises i.e., parallel bar, pommel horse) and static (maintaining a balanced inverted body position, i.e. floor exercises, rings) forms. The static form of handstand is of particular relevance as it is frequently the initial and/or the final position of many figures [5,6].

Apart from gymnastics, it is a standard skill for assessing movement literacy [7]. The capability and proficiency of performing a handstand are crucial for learning more advanced and combined elements, such as handstand to forward roll, backward roll to handstand, or handsprings [4,8]. These elements are commonly used in physical education [8] from elementary to high school levels and are frequently researched among college PE students [8–10]. As gymnastics is commonly included in the PE curriculum of primary and secondary education [11–14] across many educational systems, prospective PE teachers are supposed to be familiar with fundamental gymnastic element [11,15]. These elements may cover for example rolling, hanging, swinging, and supporting , where the handstand should be also included [11]. Apart from understanding the gymnastic element itself, it is also desirable for PE teachers to be able to demonstrate the particular element [15], as observing a performed element before learning it increased skill acquisition [16].

The quality of handstand execution is important not only in gymnastics performance evaluation but also for skill acquisition. Generally, the reached quality of performance may range from ‘fail to perform given element or not recognizable’, execution with large errors, to performances ‘without any errors’. Such evaluation is important for athletes, coaches, PE teachers, and other experts responsible for and involved in training and education. Both qualitative and quantitative scales are commonly used for such evaluations [17,18]. The Assessment of the Quality Value

(AQV; score range 0 - 4 points, 0 represents the worst (not accomplished) and 4 the best (no errors)) is one such qualitative scale used to evaluate the technical performance aspects of selected elements [17,19]. The E-score is a somewhat finer quantitative assessment option [20]. The E-score assigns decimal point values (i.e., 0.1; 0.3; 0.5; 1.0) for errors made in a particular element; more points scored designating worse performance [20].

From the perspective of performance evaluation within static position as handstand, two seconds are minimal requested duration. Shorter duration of those elements is penalized [20], and also balancing a handstand with larger corrective movements and sway results in worse performance rating (e.g., a higher score deductions for the execution [17]). Proper static handstand is characterized as a maintained balance in an inverted straight body position [21,22] with hands in contact with the ground or support surface [22]. During such handstand, arms should be in ~180° flexion [4] with extended elbows. From the perspective of performance evaluation, balancing a handstand with larger corrective movements and sway results in worse performance rating (e.g., a higher score deductions for the execution (Fink et al., 2021a)). Maintaining the static handstand is a complex interplay of various factors [23–26] mostly affected by the reciprocal coordination of the wrists, elbows, shoulders, and hips [1,5,27–30] primarily correcting for sway in the anterior-posterior direction. The wrists and wrists' torque are considered as the most important for balance maintenance [1,5,28], flexion in elbows [29] and hips [1,5,27,30] also allows for corrective movements. Interestingly, the role of shoulders to compensate for a stable position and maintaining a handstand is yet less recognized [1,23], though some authors [28,30,31] have suggested that shoulders are an important joint group influential in the center of mass (COM) shifting [1]. 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 [32].

Uzunov (2008) also discusses the need for shoulder joint flexion to maintain ~180° during a handstand.

Shoulder joint function can be divided into two capacities, mobility and stability [33]. Shoulder joint mobility and functional stability of the upper body are often assessed across sports including gymnastics [34–38], frequently by The Upper Quarter Y Balance Test (UQYBT) [39] and The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) [40].

It seems that the shoulder joint function may play a substantial role in a static handstand execution. Therefore, this study aims to examine the relationship between shoulder joint mobility and stability and the quality of handstand execution among prospective PE teachers. To do so, we compared the performances in CKCUEST and UQYBT with handstand execution scores from expert judges. We predict that participants with better scores in shoulder joint stability and mobility tests will also reach better handstand quality scores.

Materials and Methods

The study took part during the winter and summer terms in 2021 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 and informed consent before participation.

Participants

We recruited 111 first-year bachelor’s degree students (35 women and 76 men) aged 19-23 years (mean = 20.21, SD = 1.02 years) at the Faculty of Physical Education and Sport at Charles

University from Physical Education and Sport and Coaching study programmes (further sample descriptives are available in the Supplemental digital content). All participants were active athletes, who passed a semester-long "Basics of gymnastics" course focused on the fundamentals of gymnastics, including learning handstand with all necessary drills and preparatory exercises used in learning static handstand. The Basic gymnastics course curriculum does not differ between the two study programmes. In addition, before the study onset, all participants underwent two 45minute lessons directly focused on static handstands performed. On this basis, we assumed that students are able to master handstand to a sufficient degree. Only participants with no history of shoulder surgeries or acute upper limb injury were allowed to participate.

Data collection

Procedures

Data collection took place during the last lesson of the Basic gymnastics course at the end of the winter and summer terms. The participants were divided into six groups of 20. Three groups of participants were tested at the end of the summer term on 24th to 28th of May (students of Physical Education and Sport study program), and three at the end of the winter term on 6th to 10th of December (students of Coaching study program) in 2021.

Participants were familiarized with the course of the study and all testing procedures. Subsequently, they 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). Next, all participants underwent anthropometric measurements of body height, weight, and arm's length (used for UQYBT score calculation, see below). 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 as per [41]. Subsequently, the participants performed a standardized and supervised (by AP and RM) 8-minute gymnastic warm-up (mobilization and stretching) predominantly focused on the upper body and shoulder joints.

After the warm-up, each group of participants was broken down into four subgroups of 4-6 participants. The subgroups were randomly assigned to stations with the given test (1. Station – handstand performance; 2. Station – Upper Quarter Y Balance Test; 3. Station – Closed Kinetic Chain Upper Extremity Stability Test;). There were two research assistants at each station. The subgroups always continued to the next (randomized) 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. There was approximately a 40 cm wide gap between the two mats where participants were to put their hands during handstand execution (Figure 1). Participants were 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 (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) and execute the handstand directly from this position. 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.

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

-- Figure 1 --

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 [20] previously used to assess handstand execution in physical education classes by Kojima et al. (2021). This evaluation adds points 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) [39] and the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) [42]. For the UQYBT, we used the standardized procedure for the Y balance test kit [41]. 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 [39]. 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 [41], 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:

$$\text{UQYBT Right} = 100\left(\frac{\sum(\max med + \max \inf + \max sup)}{3(arm\ length)}\right)$$

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 [40]. 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 [42] with 1-minute breaks between attempts (failed attempts were not counted). Each participant began and finished the test with verbal 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 [42] and used it for the subsequent data analysis.

Data processing and statistical analysis

All data were entered into MS Excel 2016 spreadsheets, subsequently processed and analyzed using R version 4.2.1 [43] via RStudio IDE [44].

Concordance between evaluators

Kendall's coefficient of concordance from the *rcompanion* package [45] was used to assess the concordance between three AQV and E-score evaluators. We selected $W \geq 0.7$ ($p \leq 0.05$) 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.

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

-- Figure 3 ---

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 in data analysis (UQYBT Total, CKCUEST, E-score) by Fligner-Killeen's test using *fligner.test* function from *stats* package [43]. We treat the AQV as ordinal variable and therefor used non-parametric tests for their subsequent analyses.

Using the *cor.test* function from *stats* package [43], we explored associations (and possible collinearities) between variables using Pearson's r with its 95% CI (for parametrically distributed variables, i.e., UQYBT Right and UQYBT Left, UQYBT Total and CKCUEST).The threshold of close association and interchangeability was set to ≥ 0.7. If the association between a pair of variables would have reached this predefined value, we would use only one of them. Further, we used Kendall's rank correlation to assess the association between AQV and E-scores expecting a negative association between AQV and E-score because the better the execution of the handstand, the higher the score in AQV and lower the score in E-score should be.

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 [46] was used to assess the assumption of multicollinearity between predictors (i.e., UQYBT Total, CKCUEST) with a predefined level of multicollinearity < 5.0 [47]. If the VIF criterion would be greater than the predefined value, we would remove highly correlated predictors from the models [47] to avoid increasing standard errors estimates of coefficients [47,48].

We set up two ordinal logistic regression models to analyze 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). Due to the ordinal scaling of the AQV and E-score, we fitted an ordinal logistic regression (*formulas*: AQV ~ UQYBT Total + CKCUEST and E-score ~ UQYBT Total + CKCUEST) using *MASS* package [49]. We used *performance* package [50] for $R_{McFadden}^2$ and $R_{McFadden\ adj.}^2$ computations. Anova function from *car* package [46] was used for the computation of χ^2 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 [51] with a predefined alpha level for PRA of $p \geq 0.05$. 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

Table 1 shows summary statistics for individual test.

Table 1 – Sample descriptive statistics.

Variable	Mean	SD	Min	Max
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

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

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 (r_{111} = 0.78 [0.70, 0.84], $p < 0.001$). We found a weak negative and statistically non-significant correlation between UQYBT Total and CKCUEST (r_{111} = -0.05 [-0.24, 0.14], $p = 0.583$). The AQV and E-score were negatively correlated, as we expected.

The results of VIF criterion analysis regarding the multicollinearity of predictors for each subsequent regression model suggest no multicollinearity (UQYBT Total = 1.00; CKCUEST = 1.00).

Relationship between quality of handstand and stability and mobility tests

Overall, our ordinal logistic regression model for AQV reached $R_{McFadden}^2 = 0.007$ ($R_{McFadden\ adj.}^2 = -0.001$) with residual deviances 249.01 ($df_{Residual} = 105$). None of our two 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 5%. 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.

Predictor	Coefficient (β)	Std. Error	t value	p	POR	95% CI (LL, UL)	χ^2 (p)
UQYBT Total	0.05	0.04	1.30	0.19	1.05	0.98, 1.13	1.68 (0.19)
CKCUEST	-0.01	0.05	-0.27	0.79	0.99	0.89, 1.09	0.07 (0.79)

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

The second ordinal logistic regression model for E-score reached $R_{McFadden}^2 = 0.002$ ($R_{McFadden\ adj.}^2 = -0.001$) with residual deviances 565.57 ($df_{Residual} = 89$). As with our first model with AQV, none of our two 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 4%. Within the CKCUEST, every additional touch increased lead on average to 0% change in odds of being better in the E-score; in other words, the CKCUEST does not influence observed E-score in our sample.

The Brant's test of both models holds PRA for UQYBT Total ($\chi^2 = 24.02$, p = 0.20), CKCUEST ($\chi^2 = 22.93$, p = 0.24) and Omnibus ($\chi^2 = 52.35$, p = 0.06).

Predictor	Coefficient (β)	Std. Error	t value	p	POR	95% CI (LL, UL)	χ^2 (p)
UQYBT Total	-0.04	0.03	-1.13	0.26	0.96	0.91, 1.03	1.28 (0.26)
CKCUEST	0	0.05	-0.01	0.99	1	0.92, 1.09	0.00 (0.99)

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

Fig 4. Proportional odds ratios of shoulder joint function measures on AQV and E-score.

--- Figure 4 --

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

The ability to perform a handstand is an essential element in gymnastic activities [5,8] included also in PE [8,9,11]. Multiple ways of compensating sway (COM shifts) to maintain handstand position have previously been discussed in the literature [1,3,5,23,30]. However, they were mostly omitting the role of shoulders, while multiple authors argued and provided supportive evidence for shoulder joint function being an important element for handstand execution [4,21,23,28,31]. 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) field tests in a sample of prospective PE teachers. Based on our analyses, we observed that the standardized field tests of shoulder joint functioning had no statistically significant effect on either AQV or E-score rating in our sample and, thus, on the quality of handstand execution.

We used two standardized field tests (UQYBT & CKCUEST) examining aspects of shoulder joint stability and complex function. Although other studies (with smaller samples) report a moderate positive correlation between UQYBT and CKCUEST (e.g., r_{30} = 0.49; [52], our results (r_{111} = -0.05, [-0.24, 0.14]) are more in accordance with Taylor et al. (2016) (r_{257} range = 0.04-0.18), showing virtually no relationship between these two tests, supporting the claim that both tests assess different aspects of shoulder function [53].

The shoulder joint position is nearly 180° during handstand execution [32]. Thus, the level of shoulders' aROM should be an important factor contributing to maintaining a handstand. This can be seen as a considerable factor affecting our results raised against the 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 [56]. Thus, the position and load during the test should not substantially affect the observed patterns of results.

Although the UQYBT and CKCUEST tests are commonly used [34,40,52,53,57] and we have performed them in a standardized fashion and compliance with respective protocols, 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 (at least in our sample), as suggested by the shoulder joint balance strategy. The explanation for the negligible odds could lay in the difference of upper extremities positions between handstand and selected tests.

Compared to when the upper extremities are in full flexion (~ 180°) during handstand execution [32], they are in the middle flexion (~ 90°) during UQYBT and CKCUEST execution.

Although we assumed that our sample of college athlete's participants would be able to perform handstands sufficiently well, based on the performance evaluation, we found that this was not the case. The level of experience plays a role in the successful handstand execution [25], 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 (see Figure 3). This substantially skewed the observed data distribution, not allowing for better estimates of shoulder function on handstand execution. We can only conclude that performing a handstand 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). 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, which would correspond to our null findings.

Further, though the CKCUEST is a standardized test with relatively high reliability, De Oliveira et al. (2017) point out the CKCUEST is a discordant test due to systematic error and differences during measurements. 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 [53].

To conclude, we observed no association between the shoulder joint function and the quality of handstand execution in our sample. 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. Future research should aim to test the relationship between stability and mobility of the shoulder joint and the quality of handstand execution among experienced gymnasts rather than a heterogeneous sample of physical education and sports students.

Author contributions

Conceptualisation: Jan Chrudimský, Roman Malíř, Adam Provazník

Research concept and study design: Roman Malíř

Literature review: Roman Malíř

Data collection: Roman Malíř, Adam Provazník

Data analysis and interpretation: Roman Malíř, Vít Třebický

Visualisation: Roman Malíř, Vít Třebický

Writing of the manuscript: Roman Malíř, Vít Třebický

Reviewing/editing a draft of the manuscript: Roman Malíř, Jan Chrudimský, Vít Třebický, Adam Provazník

Acknowledgements

The authors are grateful to the collective of assistants who helped with the data collection and all participants for taking part in the study. We thank Bianca Maria Laoëre for English proofreading of the article.

Declaration of conflict-of-interest statement

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

Funding

This study was supported by the Cooperatio Programme, research area Sport Sciences – Biomedical & Rehabilitation Medicine (SPOB).

References

1. Kerwin D G., Trewartha G. 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. 2001;33: 1182–1188.

2. Mizutori H, Kashiwagi Y, Hakamada N, Tachibana Y, Funato K. Kinematics and joints moments profile during straight arm press to handstand in male gymnasts. Masani K, editor. PLoS ONE. 2021;16: e0253951. doi:10.1371/journal.pone.0253951

3. Sobera M, Serafin R, Rutkowska-Kucharska A. Stabilometric profile of handstand technique in male gymnasts. Acta of Bioengineering and Biomechanics; 01/2019; ISSN 1509-409X. 2019 [cited 1 Nov 2022]. doi:10.5277/ABB-01267-2018-02

4. Uzunov V. The Handstand: A Four Stage Training Model. Gym Coach. 2008;2008: 52–59. doi:10.13140/RG.2.1.2985.1363

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

6. Kochanowicz A, Kochanowicz K, Niespodzinski B, Mieszkowski J, Biskup L. The level of body balance in a handstand and the effectiveness of sports training in gymnastics. BJHPA. 2015;7: 117–124. doi:10.29359/BJHPA.07.4.11

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

8. Kojima M, Kinomura Y, Kuzuhara K. 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. 2021;21: 2087–2096. doi:10.7752/jpes.2021.s3266

9. Maleki F, Nia P, Zarghami M, Neisi A. The Comparison of Different Types of Observational Training on Motor Learning of Gymnastic Handstand. Journal of Human Kinetics. 2010;26: 13–19. doi:10.2478/v10078-010-0043-0

10. Masser LS. Critical Cues Help First-Grade Students' Achievement in Handstands and Forward Rolls. Journal of Teaching in Physical Education. 1993;12: 301–312. doi:10.1123/jtpe.12.3.301

11. Coelho J. Gymnastics and movement instruction: Fighting the decline in motor fitness. Journal of Physical Education, Recreation & Dance. 2010;81: 14–18.

12. Pajek MB, Čuk I, Kovač M, Jakše B. Implementation of the Gymnastics Curriculum in the Third Cycle of Basic School in Slovenia. / Realizacija Gimnastičnih Vsebin V Tretjem Triletju Osnovne Šole V Sloveniji. Science of Gymnastics Journal. 2010;2: 15–27. Available: https://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=55433025&site=ehost-live

13. Robinson DB, Randall L, Andrews E. Physical education teachers' (lack of) gymnastics instruction: an exploration of a neglected curriculum requirement. Curriculum Studies in Health and Physical Education. 2020;11: 67–82. doi:10.1080/25742981.2020.1715232

14. Rudd JR, Barnett LM, Farrow D, Berry J, Borkoles E, Polman R. The Impact of Gymnastics on Children's Physical Self-Concept and Movement Skill Development in Primary Schools. Measurement in Physical Education and Exercise Science. 2017;21: 92–100. doi:10.1080/1091367X.2016.1273225

15. Werner PH, Williams LH, Hall TJ. Teaching Children Gymnastics. Human Kinetics; 2012. doi:10.5040/9781718208988

16. Ashford D, Bennett SJ, Davids K. Observational modeling effects for movement dynamics and movement outcome measures across differing task constraints: a meta-analysis. J Mot Behav. 2006;38: 185–205. doi:10.3200/JMBR.38.3.185-205

17. Fink H, Hofmann D, Scholtz D. Age Group Development and Competition Program for Men's Artistic Gymnastics. Fédération Internationale de Gymnastique. 2021b; 123 pages.

18. Kovač M. Assessment of Gymnastic Skills at Physical Education - The Case of Backward Roll. Science of gymnastics journal. 2012;4.

19. Fink H, López LO, Hofmann D. Age Group Development and Competition Program for Women's Artistic Gymnastics. Fédération Internationale de Gymnastique. 2021a; 127 pages.

20. International Gymnastics Federation. 2022-2024 Code of points: men's artistic gymnastics. 2022 [cited 2 Dec 2022]. Available: https://www.gymnastics.sport/publicdir/rules/files/en_%202022-2024%20MAG%20CoP.pdf

21. Pryhoda M, Newell K, Irwin G. Handstand balance motor control mechanisms. ISBS Proceedings Archive. 2021;39: 212. Available: https://commons.nmu.edu/isbs/vol39/iss1/55

22. Wyatt HE, Gittoes MJR, Irwin G. Sport-specific musculoskeletal growth and postural control in female artistic gymnasts: a 12 month cohort study. Sports Biomech. 2020;19: 258–270. doi:10.1080/14763141.2018.1469662

23. Gautier G, Marin L, Leroy D, Thouvarecq R. Dynamics of expertise level: Coordination in handstand. Human Movement Science. 2009;28: 129–140. doi:10.1016/j.humov.2008.05.003

24. Krištofič J, Maly T, Zahálka F. The effect of intervention balance program on postural stability. Science of Gymnastics Journal. 2018;10: 17–28.

25. Omorczyk J, Bujas P, Puszczałowska-Lizis E, Biskup L. Balance in handstand and postural stability in standing position in athletes practicing gymnastics. Acta of Bioengineering and Biomechanics; 02/2018; ISSN 1509-409X. 2018 [cited 1 Nov 2022]. doi:10.5277/ABB-01110-2018-02

26. Shumway-Cook A, Woollacott MH. Motor control: translating research into clinical practice. 4th ed. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2012.

27. Blenkinsop GM, Pain MTG, Hiley MJ. Balance control strategies during perturbed and unperturbed balance in standing and handstand. R Soc open sci. 2017;4: 161018. doi:10.1098/rsos.161018

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

29. Slobounov SM, Newell KM. Postural Dynamics in Upright and Inverted Stances. Journal of Applied Biomechanics. 1996;12: 185–196. Available: https://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=20751616&site=ehost-live

30. Yeadon MR, Trewartha G. Control Strategy for a Hand Balance. Motor Control. 2003;7: 421–442. doi:10.1123/mcj.7.4.421

31. Prassas SG, Kelley DL, Pike NL. Shoulder joint torques and the straight arm/flexed hips press handstand on the parallel bars. ISBS-Conference Proceedings Archive. 1986.

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

33. Veeger HEJ, van der Helm FCT. Shoulder function: The perfect compromise between mobility and stability. Journal of Biomechanics. 2007;40: 2119–2129. doi:10.1016/j.jbiomech.2006.10.016

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

35. Borsa PA, Laudner KG, Sauers EL. Mobility and Stability Adaptations in the Shoulder of the Overhead Athlete. Sports Med. 2008;38: 17–36. doi:10.2165/00007256-200838010-00003

36. Hill L, Collins M, Posthumus M. Risk factors for shoulder pain and injury in swimmers: A critical systematic review. The Physician and Sportsmedicine. 2015;43: 412–420. doi:10.1080/00913847.2015.1077097

37. Nuhmani S. Correlation between Core Stability and Upper-Extremity Performance in Male Collegiate Athletes. Medicina. 2022;58: 982. doi:10.3390/medicina58080982

38. Zarei M, Eshghi S, Hosseinzadeh M. The effect of a shoulder injury prevention programme on proprioception and dynamic stability of young volleyball players; a randomized controlled trial. BMC Sports Sci Med Rehabil. 2021;13: 71. doi:10.1186/s13102-021-00300-5

39. Gorman PP, Butler RJ, Plisky PJ, Kiesel KB. Upper Quarter Y Balance Test: reliability and performance comparison between genders in active adults. J Strength Cond Res. 2012;26: 3043–3048. doi:10.1519/JSC.0b013e3182472fdb

40. De Oliveira VMA, Pitangui ACR, Nascimento VYS, da Silva HA, dos Passos MHP, de Araújo RC. Test-retest reliability of the closed kinetic chain upper extremity stability test (CKCUEST) in adolescents. Int J Sports Phys Ther. 2017;12: 125–132. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5294939/

41. Cook G. Movement: functional movement systems: screening, assessment, and corrective strategies. Aptos, CA: On Target Publications; 2010.

42. Tucci HT, Martins J, Sposito G de C, Camarini PMF, de Oliveira AS. Closed Kinetic Chain Upper Extremity Stability test (CKCUES test): a reliability study in persons with and without shoulder impingement syndrome. BMC musculoskeletal disorders. 2014;15: 1–9. doi:10.1186/1471-2474-15-1

43. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.; 2022. Available: https://www.R-project.org/.

44. RStudio Team. RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA; 2022. Available: http://www.rstudio.com/

45. Mangiafico S. _rcompanion: Functions to Support Extension Education Program Evaluation_. R package version 2.4.18. 2022. Available: https://CRAN.R-project.org/package=rcompanion

46. Fox J, Weisberg S, Price B, Adler D, Bates D, Baud-Bovy G, et al. car: Companion to Applied Regression. 2022. Available: https://CRAN.R-project.org/package=car

47. Akinwande MO, Dikko HG, Samson A. Variance Inflation Factor: As a Condition for the Inclusion of Suppressor Variable(s) in Regression Analysis. Open Journal of Statistics. 2015;05: 754. doi:10.4236/ojs.2015.57075

48. Miles J. Tolerance and Variance Inflation Factor. Wiley StatsRef: Statistics Reference Online. John Wiley & Sons, Ltd; 2014. doi:10.1002/9781118445112.stat06593

49. Ripley B, Venables B, Bates DM, ca 1998) KH (partial port, ca 1998) AG (partial port, Firth D. MASS: Support Functions and Datasets for Venables and Ripley’s MASS. 2022. Available: https://CRAN.R-project.org/package=MASS

50. Lüdecke D, Makowski D, Ben-Shachar MS, Patil I, Waggoner P, Wiernik BM, et al. performance: Assessment of Regression Models Performance. 2022. Available: https://CRAN.R-project.org/package=performance

51. Schlegel B, Steenbergen M. brant: Test for Parallel Regression Assumption. 2022; 3. Available: https://benjaminschlegel.ch/r/brant/

52. Westrick RB, Miller JM, Carow SD, Gerber JP. Exploration of the Y-Balance Test for Assessment of Upper Quarter Closed Kinetic Chain Performance. Int J Sports Phys Ther. 2012;7: 139–147. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3325634/

53. Taylor JB, Wright AA, Smoliga JM, DePew JT, Hegedus EJ. Upper-Extremity Physical-Performance Tests in College Athletes. Journal of Sport Rehabilitation. 2016;25: 146–154. doi:10.1123/jsr.2014-0296

54. Mkaouer B, Hammoudi-Nassib S, Amara S, Chaabène H. Evaluating the physical and basic gymnastics skills assessment for talent identification in men's artistic gymnastics proposed by the International Gymnastics. bs. 2018;35: 383–392. doi:10.5114/biolsport.2018.78059

55. Vernetta M, Peláez-Barrios EM, López-Bedoya J. Systematic review of flexibility tests in gymnastics. jhse. 2020;17. doi:10.14198/jhse.2022.171.07

56. Wattanaprakornkul D, Halaki M, Boettcher C, Cathers I, Ginn KA. A comprehensive analysis of muscle recruitment patterns during shoulder flexion: An electromyographic study. Clin Anat. 2011;24: 619–626. doi:10.1002/ca.21123

57. Schwiertz G, Beurskens R, Muehlbauer T. Discriminative validity of the lower and upper quarter Y balance test performance: a comparison between healthy trained and untrained youth. BMC Sports Sci Med Rehabil. 2020;12: 73. doi:10.1186/s13102-020-00220-w