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**Section I – Kinesiology**


# Upper Limb Neuromuscular Characteristics during a Press Handstand on Parallel Bars in Young (10–12 Years Old) and Adult Male Artistic Gymnasts

*by*
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*A press handstand on parallel bars (PHPB) is one of the fundamental gymnastic skills. While for adult gymnasts (AGs) this exercise is relatively easy, many young gymnasts (YGs) find it difficult to perform correctly, not due to the lack of muscular strength but because of poor neuromuscular control. Therefore, the aim of the study was to evaluate muscle activity during the PHPB in YGs and AGs, and to compare the neuromuscular control of gymnasts capable of performing the PHPB with that of YGs not capable of performing the PHPB. The study involved 41 male artistic gymnasts. Twenty-five were YGs (11.08 ± 0.55 years), of whom 12 were capable of performing the PHPB (YGs-C) and 13 were not (YGs-N); the remaining 16 participants were AGs (24.04 ± 12.92 years). Upper body muscle activity was evaluated by surface electromyography during the PHPB and shoulder joint complex flexion in two positions: 80° and 160°. Almost all investigated muscles (upper trapezius, deltoid anterior, biceps brachii, infraspinatus, pectoralis major, triceps brachii, latissimus dorsi) showed significantly (31%–136%, $p \leq 0.05$) higher muscle activity in YGs-C during the PHPB as compared with AGs, except the serratus anterior muscle. The serratus anterior was also the only muscle that exhibited significantly higher activity ($p \leq 0.05$), reaching up to 63%, in YGs-C in comparison with YGs-N at 160° of shoulder joint complex flexion. Improving scapular control at 160° of shoulder joint complex flexion, especially by strengthening the serratus anterior muscle, can contribute to successful PHPB performance in YGs.*

***Keywords**: neuromuscular efficiency; coactivation index; surface electromyography; artistic gymnastics*

## Introduction

A press handstand on parallel bars (PHPB) is typically described as a slow and controlled elevation of the body from a stationary position to a handstand position (Prassas, 1988). This fundamental gymnastic skill must be developed to perform more complex and demanding exercises. It demands both muscle strength, especially of shoulder joint flexors, and remarkable flexibility in hip joints. One of the forms of the PHPB is a straight arms bent body (L-sit position) to handstand. A press handstand can be also performed in a straddled form, which is less difficult owing to distance reduction of lower limb mass from the shoulder joint and thus a limited moment of gravity (Mizutori et al., 2021).

While the PHPB execution is not difficult for experienced adult gymnasts (AGs), it appears challenging among young novice gymnasts. Typically, the lack of flexibility in young gymnasts (YGs) is not the reason for failed attempts at this exercise (Prassas et al., 1986); thus, the reason should lie within muscle strength or/and neuromuscular control (Milosis, 2023). Shoulder joint complex flexors must produce torque that would overcome the gravitational moment of the trunk and lower limbs, at the same time

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maintaining the centre of body mass above the wrist joints to maintain balance (Mizutori et al., 2021; Prassas, 1988). Although the magnitude of shoulder joint moments during the PHPB is more than three times the body weight, Prassas (1988) pointed out that unsuccessful press handstand in gymnasts was rather due to poor motor coordination than lack of muscular strength. It was already suggested many years ago by Prassas et al. (1986) that gymnasts with the highest torque production at 135° in the shoulder joint complex performed better in the PHPB; however, this was only developed in a limited scope. In this regard, it is important to investigate neuromuscular control of the shoulder joint complex not only in one joint position (typically 90° of flexion), as this complex, besides the glenohumeral joint, comprises also acromioclavicular and sternoclavicular joints, which are utilized more in the second half of the range of motion (90–180°) (Teece et al., 2008; Zhu et al., 2024).

Many studies have explored the biomechanics and motor control in skill development and technique execution in artistic gymnastics (Farana et al., 2023; Hernández-Beltrán et al., 2023; Malir et al., 2023). The research included analysis of many exercises on various apparatuses, including parallel bars (Velickovic et al., 2016, 2025). Among others, it was shown that YGs exhibited higher overall muscle activity during the handstand on parallel bars in comparison with AGs (Kochanowicz et al., 2019). On the other hand, kinematic and kinetic analyses of the PHPB (Prassas, 1988; Rajpoot et al., 2017) provided no information about muscle activity during this exercise or the child-adult differences. Information on proper neuromuscular control during the PHPB in AGs and on how it deviates in YGs could provide basis for conditioning guidelines that would help master the skill. Therefore, the aim of the study was twofold: 1) to evaluate muscle activity during the PHPB in YGs and AGs; and 2) to evaluate and compare their neuromuscular performance outcome with that of YGs who were not capable of performing the PHPB (YGs-N). We hypothesized that the muscle activity during the PHPB would be higher in YGs in comparison with AGs, and that the neuromuscular performance of YGs would vary depending on their ability to perform the PHPB.

## Methods

### *Experimental Overview*

In this cross-sectional study, the muscle activity of YGs and AGs during the PHPB was investigated via surface electromyography (SEMG). In addition, muscle activity in terms of neuromuscular efficiency and coactivation in YGs-N was compared with that in their peers who were capable to perform this exercise (YGs-C) and in AGs. During the initial visit, all procedures were explained to participants and basic anthropometric characteristics were measured. During proper testing, firstly, athletes performed a standardized warm-up in a gymnastic hall and then the SEMG setup preparation took place. The duration and thoroughness of the warm-up were carefully controlled to ensure optimal conditions for neuromuscular performance (Lee et al., 2024). After that, the PHPB (only among those that were capable of) was performed, followed by maximal voluntary contraction (MVC) and neuromuscular performance assessments.

### *Participants*

The study involved 41 male artistic gymnasts. Twenty-five of them were youth prospective athletes (YGs, aged 11.08 ± 0.55 years) and the remaining participants (n = 16) included adult elite artistic gymnasts of the Polish national team (AGs, aged 24.04 ± 12.92 years). In addition, YGs were divided into two groups: 1) YGs-C and 2) YGs-N. Both groups of YGs trained in the same gymnastic club and their training routines were similar. The inclusion criteria for the study required that all participants had started their gymnastic training at the age of 6–7 years, were either 10–12 years old or an adult elite gymnast and were able to perform a seated straddle (90°) forward bend with their torso lying on the floor. Participants were excluded if they had orthopaedic or neural disorder that could potentially affect the outcome of the study. Detailed characteristics of each group are shown in Table 1.

The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee at the Regional Medical Chamber in Gdansk, Gdansk, Poland (approval number: KB-12/15; approval date: 14 July 2015). All participants or their legal guardians provided their informed consent to participate in the study.

***Procedures***

*Surface Electromyography*

In the study, the following muscles of the dominant side (handwriting preference) were investigated with SEMG: upper trapezius (UT), deltoid anterior (DA), biceps brachii (BB), serratus anterior (SA), infraspinatus (IS), pectoralis major's sternocostal part (PM), triceps brachii (TB), and latissimus dorsi (LD). Electromyography signals were gathered in accordance with the SENIAM recommendations (Hermens et al., 1999), which included: using Ag/AgCl electrodes with 1 $cm^2$ of the active area (Sorimex, Toruń, Poland) with an interelectrode distance of 2 cm, shaving skin if necessary, scrubbing the stratum corneum of the epidermis, and cleaning with alcohol. The electromyograph used in the study was a TeleMyo DTS system by Noraxon (Scottsdale, AZ, USA) with a sampling rate of 1500 Hz, a 10–500-Hz bandpass filter, a base gain of 500, input impedance of above 100 MΩ, and a common mode rejection exceeding 100 dB. Raw data were recorded and stored with the MyoResearch 1.08 software by Noraxon (Scottsdale, AZ, USA) and subsequently processed offline. The SEMG data were fully rectified and smoothed by calculating the root mean square (RMS, mV) values with the use of 100-ms time windows. The SEMG recordings included the following conditions: the PHPB, MVC testing, and neuromuscular performance assessment.

*Press Handstand on Parallel Bars*

Twelve YGs-C and 16 AGs performed the PHPB. This exercise was analysed in three phases: 1) an L-sit position, 2) a press, and 3) a handstand position (Figure 1). The first phase consisted of supporting the whole body above the parallel bars by hands holding each of the bars and maintaining straight legs and feet while keeping hip joints flexed in 90° (parallel to the bars) for three seconds. Subsequently, in the second phase, gymnasts pressed to the handstand with straight arms by flexion in the shoulder joint complex, which resulted in trunk and lower limb displacement toward an inverted position. During that phase, the participants' legs were straddled and brought back together only at the end of the phase. Finally, athletes maintained the handstand position on parallel bars for at least three seconds.

The PHPB belongs to element group II (elements in support or through support on 2 bars) according to the official rules in men's artistic gymnastics by the International Gymnastics Federation (FIG, 2024). The first phase of performing the PHPB has been assigned a difficulty value of 0.1, and the second and third phases together present a difficulty value of 0.2, where the maximum difficulty of an exercise can reach the value of 0.8. The correctness of the exercise was supervised by a researcher with refereeing qualifications at the national level. In AGs, the whole exercise had to be performed in a smooth manner to be counted as correct. If any error during the performance was observed, such an attempt was repeated. For YGs, it was allowed to deduct 0.1 point error (for example, because of a wrong feet position during the transition between L-sit and press phases) unless it concerned the upper body. There was a three-minute rest interval between the subsequent repetitions. To distinguish each phase for the analysis, the exercise was recorded on a camcorder (acA2000-340kc, Basler AG, Ahrensburg, Germany) placed on a side of the parallel bars and synchronized with simultaneous SEMG recording. Three correct performances were taken into further SEMG analysis.

*Maximal Voluntary Contraction*

To normalize the SEMG amplitude, MVC under isometric conditions was performed. For muscles acting in the shoulder joint complex, an isokinetic dynamometer Biodex System 4 Pro was used (Biodex Medical Systems, Inc., Shirley, NY, USA). The device setup for evaluating shoulder flexion and extension in the position of 80° of flexion in the shoulder joint, including the participant's position, and the alignment of the dynamometer arm shaft were in accordance with the manufacturers' guidelines. The position of 80° was chosen to ensure that the assessment was limited to a single joint (glenohumeral), as in a more flexed position, the possibility of the movement of the scapula in the acromioclavicular joint increases (Huberman et al., 2020). During testing, gymnasts were asked to flex or extend their arm as forcefully as they could and maintain that contraction for three seconds. The task was repeated three times for both flexion and extension. During each MVC, athletes received vigorous verbal encouragement to maximize their

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performance. The peak torque values and the SEMG signal corresponding to the contraction were taken for further analysis. The muscle activity during maximal isometric shoulder flexion served to normalize the SEMG amplitude of the UT, DA, BB, and SA muscles, while the maximal isometric shoulder extension was used for the IS, PM, TB, and LD muscles.

*Neuromuscular Performance*

To evaluate neuromuscular performance related to the PHPB, 20% and 50% MVC tasks of flexion in two positions (80° and 160°) of the shoulder complex were performed. The neuromuscular performance assessment was carried out with the same device and settings as during the MVC assessment. During the task, the participant's current torque value, as well as the target torque (20% or 50%) of the prerecorded MVC during flexion were displayed (visual feedback) on a monitor in front of the gymnast. The task was to match the current torque with the target value and sustain it for three seconds. The task was repeated three times in each position and with the target value. The testing position and target torque order were randomized for each individual. The two joint positions were chosen to test muscles under conditions where the glenohumeral joint was mostly involved (80°) or both the glenohumeral and acromioclavicular joints (160°) were involved in the activity. The different target torques (20% and 50% MVC) were chosen to assess neuromuscular performance under conditions where presumably different amounts and/or types of motor units were involved, according to the size principle of motor unit recruitment (Henneman et al., 1965). SEMG of upper body muscles was recorded during these tasks and the RMS of each agonistic (UT, DA, BB, SA) and each antagonistic (IS, PM, TB, LD) muscles normalized to muscle activity during MVC served as particular muscle's neuromuscular efficiency (Aragao et al., 2015; Mawston et al., 2021) and coactivation indices (Ervilha et al., 2012), respectively.

*Data Processing*

To reduce the intraindividual variability of electromyographic signals, the results were calculated as the average value of three repetitions of each investigated activity. To reduce interindividual variability, the RMS was normalized (NRMS) to the signal recorded during MVC. This was calculated as the peak value recorded during a one-second time frame taken from the middle two seconds of the MVC performance.

In the study, the following SEMG outcomes were analysed: mean NRMS during each phase of the PHPB and mean NRMS during the 20% and 50% MVC tasks.

***Statistical Analysis***

Differences in the anthropometric and muscle strength characteristics between the groups were assessed with the use of one-way analysis of variance (ANOVA). Two-way ANOVA with repeated measures (2 groups: YGs, AGs × 3 phases: L-sit, press, handstand) was applied to investigate differences in muscle activity between YGs-C and AGs during the PHPB. Another two-way ANOVA with repeated measures (3 × 2) was performed to determine the neuromuscular efficiency and coactivation between the groups of gymnasts (YGs-C, YGs-N, and AGs) in two joint positions of the shoulder joint complex (80° and 160°). In the event of a significant interaction, the Tukey's post-hoc test was performed to evaluate differences in particular subgroups. Normal distribution and homogeneity of variance were checked by the Shapiro-Wilk and Levene's tests, respectively. In addition, the effect size was estimated by eta-squared statistics ($\eta^2$). Values equal to or greater than 0.01, 0.06, and 0.14 indicated a small, moderate, and large effect, respectively. All calculations were performed in the Statistica 14 software (StatSoft, Tulsa, OK, United States). Differences were considered statistically significant at $\alpha \leq 0.05$. The required sample size was estimated using G*Power ver. 3.19.4 software (Faul et al., 2007). The power analysis for interaction between analysed factors in two-way ANOVA of repeated measures indicated that the minimal total sample size for the medium effect size with the power of 0.80 and the correlation among repeated measures of 0.6 was n = 36 subjects. None of the participants dropped out of the study, and a total of 41 participants were ultimately included in the analysis, resulting in a statistical power of 0.88.

## Results

### *Press Handstand on Parallel Bars*

The mean NRMS values during each phase of the PHPB in YGs-C and AGs are depicted in Figure 2. The results of two-way ANOVA with repeated measures of muscle activity during the PHPB are presented in Table 2. The group factor effect was observed in the UT, DA, PM, and BB muscles, where YGs-C had 33.6% ($F_{1,26} = 6.67$; $p = 0.02$; $\eta^2 = 0.21$), 28.1% ($F_{1,26} = 5.06$; $p = 0.03$; $\eta^2 = 0.16$), 61.9% ($F_{1,26} = 10.19$; $p < 0.01$; $\eta^2 = 0.28$), 136.7% ($F_{1,26} = 5.17$; $p = 0.03$; $\eta^2 = 0.17$) higher NRMS values in comparison with AGs, respectively, regardless of the PHPB phase.

The phase factor effect was observed in every studied muscle. In the UT ($F_{2,52} = 203.67$; $p < 0.01$; $\eta^2 = 0.89$), DA ($F_{2,52} = 212.52$; $p < 0.01$; $\eta^2 = 0.89$), and SA ($F_{2,52} = 108.17$; $p < 0.01$; $\eta^2 = 0.81$) muscles, the highest NRMS values were reported during the press phase, followed by the handstand and L-sit phases, regardless of the group allocation. In the PM ($F_{2,52} = 29.97$; $p < 0.01$; $\eta^2 = 0.53$) and LD ($F_{2,52} = 15.88$; $p < 0.01$; $\eta^2 = 0.38$) muscles, the level of activity during the L-sit and press phases was similar and from two- to threefold higher than in the handstand phase. Regarding the BB ($F_{2,52} = 29.76$; $p < 0.01$; $\eta^2 = 0.53$) activity, the highest NRMS values were noted in the press phase as compared with the L-sit and handstand phases. In turn, the TB ($F_{2,52} = 12.69$; $p < 0.01$; $\eta^2 = 0.33$) muscle presented the highest activity during the L-sit phase as compared with the remaining phases. The IS was the only muscle that showed an interaction of group and phase factors effect ($F_{2,52} = 5.78$; $p < 0.01$; $\eta^2 = 0.18$). This interaction is depicted in Figure 2.

### *Neuromuscular Performance*

The mean NRMS values during submaximal isometric contraction (flexion) in the shoulder complex of agonistic muscles (neuromuscular efficiency) and antagonistic muscles (coactivation) are presented in Figures 3 and 4, respectively. The results of two-way ANOVA with repeated measures of muscle activity during submaximal isometric contraction (flexion) in the shoulder complex are shown in Table 3.

The UT ($F_{2,37} = 3.89$; $p = 0.03$; $\eta^2 = 0.17$) and BB ($F_{2,37} = 3.49$; $p = 0.04$; $\eta^2 = 0.16$) muscles in the 20% MVC task showed a group factor effect, where AGs had about 37.1% and 48.6% significantly lower muscle activity in comparison with the remaining groups, respectively, regardless of the joint position. Conversely, the DA muscle activity in the 50% MVC task was significantly higher by 39.3% ($F_{2,37} = 6.03$; $p < 0.01$; $\eta^2 = 0.25$) in AGs in comparison with YGs-N. Overall, each agonistic muscle (UT, DA, BB, SA) exhibited a joint position factor effect, where muscle activity in the joint position of 160° of the shoulder joint complex was higher than in 80° in each studied group during both 20% and 50% MVC tasks, except for the BB muscle, for which that was true only during the 50% MVC task ($F_{1,37} = 8.02$; $p < 0.01$; $\eta^2 = 0.18$). The SA muscle in the 20% ($F_{2,37} = 4.51$; $p = 0.02$; $\eta^2 = 0.20$) and 50% MVC ($F_{2,37} = 6.35$; $p < 0.01$; $\eta^2 = 0.26$) tasks also presented a group factor effect, where YGs-N had lower muscle activity in comparison with other groups, regardless of the joint position. However, the interaction of group and joint factors effect ($F_{2,37} = 6.01$ and 8.86; $p < 0.01$; $\eta^2 = 0.25$ and 0.32 for 20% and 50% MVC, respectively) implied that this result was mainly due to the differences between YGs-N and the rest of gymnasts in the position of 160° of the shoulder joint complex. The outcome of interaction analysis for the SA muscle is depicted in Figure 3.

No main group factor effect was observed among the antagonistic muscles. Similarly to the agonistic muscles, each antagonistic muscle showed a joint position factor effect in both 20% and 50% MVC tasks. For LD ($F_{1,37} = 14.69$ and 9.00; $p < 0.01$; $\eta^2 = 0.28$ and 0.20 for 20% and 50% MVC, respectively), TB ($F_{1,37} = 18.62$ and 54.49; $p < 0.01$; $\eta^2 = 0.33$ and 0.60 for 20% and 50% MVC, respectively), and IS ($F_{1,37} = 26.41$ and 31.80; $p < 0.01$; $\eta^2 = 0.42$ and 0.46 for 20% and 50% MVC, respectively) muscles, muscle activity in the position of 160° in the shoulder joint complex was by about 35.4%, 60.8%, and 63.7% higher in comparison with the 80° position, respectively, regardless of the group. Contrary, the PM ($F_{1,37} = 32.16$ and 36.78; $p < 0.01$; $\eta^2 = 0.47$ and 0.50 for 20% and 50% MVC, respectively) muscle presented about 51.2% lower muscle activity in 160° of the shoulder joint complex in comparison with the 80° position. LD (20% MVC: $F_{2,37} = 9.65$; $p < 0.01$; $\eta^2 = 0.34$ and 50% MVC: $F_{2,37} = 7.44$; $p < 0.01$; $\eta^2 = 0.29$ task) and TB (50% MVC task; $F_{2,37} = 3.71$; $p = 0.03$; $\eta^2 = 0.17$) muscles exhibited a significant interaction between the group and joint position effect, which is depicted in Figure 4.

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**Table 1.** Anthropometric and shoulder muscle strength characteristics of young and adult gymnasts (mean ± standard deviation).

| Variable | Young gymnasts not capable of pressing to the handstand (n = 13) | Capable of pressing to the handstand | | *p* | $\eta^2$ |
|---|---|---|---|---|---|
| | | Young gymnasts (n = 12) | Adult gymnasts (n = 16) | | |
| Age (years) | 11.07 ± 0.38 | 11.10 ± 0.71 | 24.04 ± 12.92** | < 0.01 | 0.39 |
| Body height (cm) | 140.58 ± 6.43 | 142.25 ± 7.29 | 161.66 ± 37.94* | 0.04 | 0.15 |
| Body mass (kg) | 33.06 ± 4.21 | 35.87 ± 5.94 | 69.01 ± 6.08*** | < 0.01 | 0.91 |
| Peak torque – extension (Nm) | 33.77 ± 6.83 | 37.33 ± 9.49 | 112.96 ± 21.42*** | < 0.01 | 0.87 |
| Peak torque – extension / body mass ($Nm \cdot kg^{-1}$) | 101.57 ± 11.69 | 103.5 ± 16.56 | 162.59 ± 28.97*** | < 0.01 | 0.67 |
| Peak torque – flexion (Nm) | 26.76 ± 5.93 | 30.09 ± 6.90 | 94.89 ± 14.06*** | < 0.01 | 0.92 |
| Peak torque – flexion / body mass ($Nm \cdot kg^{-1}$) | 80.76 ± 13.29 | 83.72 ± 11.88 | 136.38 ± 15.55*** | < 0.01 | 0.80 |
| Ratio of flexion/extension | 79.95 ± 11.88 | 81.50 ± 8.06 | 85.34 ± 12.09 | 0.40 | 0.05 |

*Significant difference with two other groups at p * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001*

**Table 2.** Two-way ANOVA with repeated measures (2 groups × 3 phases) of muscle activity during the press handstand in young and adult gymnasts.

| Muscle | Effect | F (df) | *p* | $\eta^2$ |
|---|---|---|---|---|
| Upper trapezius | Group | 6.67 (1, 26) | 0.02* | 0.21 |
| | Phase | 203.67 (2, 52) | < 0.01*** | 0.89 |
| | Group × phase interaction | 2.03 (2, 52) | 0.14 | 0.07 |
| Deltoid anterior | Group | 5.06 (1, 26) | 0.03* | 0.16 |
| | Phase | 212.52 (2, 52) | < 0.01*** | 0.89 |
| | Group × phase interaction | 1.18 (2, 52) | 0.31 | 0.04 |
| Infraspinatus | Group | 3.46 (1, 26) | 0.07 | 0.12 |
| | Phase | 18.63 (2, 52) | < 0.01*** | 0.42 |
| | Group × phase interaction | 5.78 (2, 52) | < 0.01** | 0.18 |
| Pectoralis major | Group | 10.19 (1, 26) | < 0.01** | 0.28 |
| | Phase | 29.97 (2, 52) | < 0.01*** | 0.53 |
| | Group × phase interaction | 0.30 (2, 52) | 0.74 | 0.01 |
| Biceps brachii | Group | 5.17 (1, 26) | 0.03* | 0.17 |
| | Phase | 29.76 (2, 52) | < 0.01*** | 0.53 |
| | Group × phase interaction | 3.15 (2, 52) | 0.06 | 0.11 |
| Triceps brachii | Group | 2.85 (1, 26) | 0.10 | 0.10 |
| | Phase | 12.69 (2, 52) | < 0.01*** | 0.33 |
| | Group × phase interaction | 1.51 (2, 52) | 0.23 | 0.05 |
| Latissimus dorsi | Group | 0.25 (1, 26) | 0.62 | 0.01 |
| | Phase | 15.88 (2, 52) | < 0.01*** | 0.38 |
| | Group × phase interaction | 0.77 (2, 52) | 0.47 | 0.03 |
| Serratus anterior | Group | 0.15 (1, 26) | 0.71 | 0.01 |
| | Phase | 108.17 (2, 52) | < 0.01*** | 0.81 |
| | Group × phase interaction | 1.29 (2, 52) | 0.28 | 0.05 |

*df: degrees of freedom; significant difference at p * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001*

**Table 3.** Two-way ANOVA with repeated measures (3 groups: YGs-N, YGs-C, AGs × 2 joint positions: 80°, 160°) of muscle activity during submaximal isometric contraction (flexion) in the shoulder complex.

| Muscle | Intensity | Effect | F (df) | *p* | $\eta^2$ |
|---|---|---|---|---|---|
| Upper trapezius | 20% MVC | Group | 3.89 (2, 37) | 0.03* | 0.17 |
| | | Joint position | 50.18 (1, 37) | 0.01*** | 0.58 |
| | | Group × joint position interaction | 0.01 (2, 37) | 0.99 | 0.01 |
| | 50% MVC | Group | 0.49 (2, 36) | 0.61 | 0.03 |
| | | Joint position | 50.66 (1, 36) | 0.01*** | 0.58 |
| | | Group × joint position interaction | 0.51 (2, 36) | 0.60 | 0.03 |
| Deltoid anterior | 20% MVC | Group | 1.31 (2, 37) | 0.28 | 0.07 |
| | | Joint position | 18.02 (1, 37) | 0.01*** | 0.33 |
| | | Group × joint position interaction | 1.34 (2, 37) | 0.27 | 0.07 |
| | 50% MVC | Group | 6.03 (2, 37) | 0.01** | 0.25 |
| | | Joint position | 7.72 (1, 37) | 0.01** | 0.17 |
| | | Group × joint position interaction | 2.58 (2, 37) | 0.09 | 0.12 |
| Biceps brachii | 20% MVC | Group | 3.49 (2, 37) | 0.04* | 0.16 |
| | | Joint position | 1.11 (1, 37) | 0.30 | 0.03 |
| | | Group × joint position interaction | 0.01 (2, 37) | 0.99 | 0.01 |
| | 50% MVC | Group | 1.77 (2, 37) | 0.18 | 0.09 |
| | | Joint position | 8.02 (1, 37) | 0.01** | 0.18 |
| | | Group × joint position interaction | 0.61 (2, 37) | 0.55 | 0.03 |
| Serratus anterior | 20% MVC | Group | 4.51 (2, 37) | 0.02* | 0.20 |
| | | Joint position | 53.15 (1, 37) | 0.01*** | 0.59 |
| | | Group × joint position interaction | 6.01 (2, 37) | 0.01** | 0.25 |
| | 50% MVC | Group | 6.35 (2, 37) | 0.01** | 0.26 |
| | | Joint position | 76.52 (1, 37) | 0.01*** | 0.67 |
| | | Group × joint position interaction | 8.86 (2, 37) | 0.01*** | 0.32 |
| Latissimus dorsi | 20% MVC | Group | 0.44 (2, 37) | 0.65 | 0.02 |
| | | Joint position | 14.69 (1, 37) | 0.01*** | 0.28 |
| | | Group × joint position interaction | 9.65 (2, 37) | 0.01*** | 0.34 |
| | 50% MVC | Group | 0.38 (2, 37) | 0.69 | 0.02 |
| | | Joint position | 9.00 (1, 37) | 0.01** | 0.20 |
| | | Group × joint position interaction | 7.44 (2, 37) | 0.01** | 0.29 |
| Pectoralis major | 20% MVC | Group | 0.70 (2, 37) | 0.50 | 0.04 |
| | | Joint position | 32.16 (1, 37) | 0.01*** | 0.47 |
| | | Group × joint position interaction | 1.87 (2, 37) | 0.17 | 0.09 |
| | 50% MVC | Group | 0.39 (2, 37) | 0.68 | 0.02 |
| | | Joint position | 36.78 (1, 37) | 0.01*** | 0.50 |
| | | Group × joint position interaction | 0.50 (2, 37) | 0.61 | 0.03 |
| Triceps brachii | 20% MVC | Group | 1.44 (2, 37) | 0.25 | 0.07 |
| | | Joint position | 18.62 (1, 37) | 0.01*** | 0.33 |
| | | Group × joint position interaction | 0.06 (2, 37) | 0.94 | 0.01 |
| | 50% MVC | Group | 0.09 (2, 37) | 0.92 | 0.01 |
| | | Joint position | 54.49 (1, 37) | 0.01*** | 0.60 |
| | | Group × joint position interaction | 3.71 (2, 37) | 0.03* | 0.17 |
| Infraspinatus | 20% MVC | Group | 1.50 (2, 37) | 0.24 | 0.08 |
| | | Joint position | 26.41 (1, 37) | 0.01*** | 0.42 |
| | | Group × joint position interaction | 2.28 (2, 37) | 0.12 | 0.11 |
| | 50% MVC | Group | 0.16 (2, 37) | 0.85 | 0.01 |
| | | Joint position | 31.80 (1, 37) | 0.01*** | 0.46 |
| | | Group × joint position interaction | 2.43 (2, 37) | 0.10 | 0.12 |

*YGs-N: young gymnasts not capable of performing the press handstand; YGs-C: young gymnasts capable of performing the press handstand; AGs: adult gymnasts; df: degrees of freedom; MVC: maximal voluntary contraction; significant difference at p * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001*

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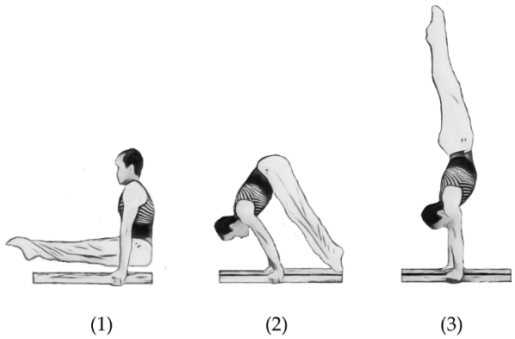


**Figure 1.** Visualisation of press handstand on parallel bars phases.
*L-sit position phase (1); press phase (2); handstand position phase (3)*

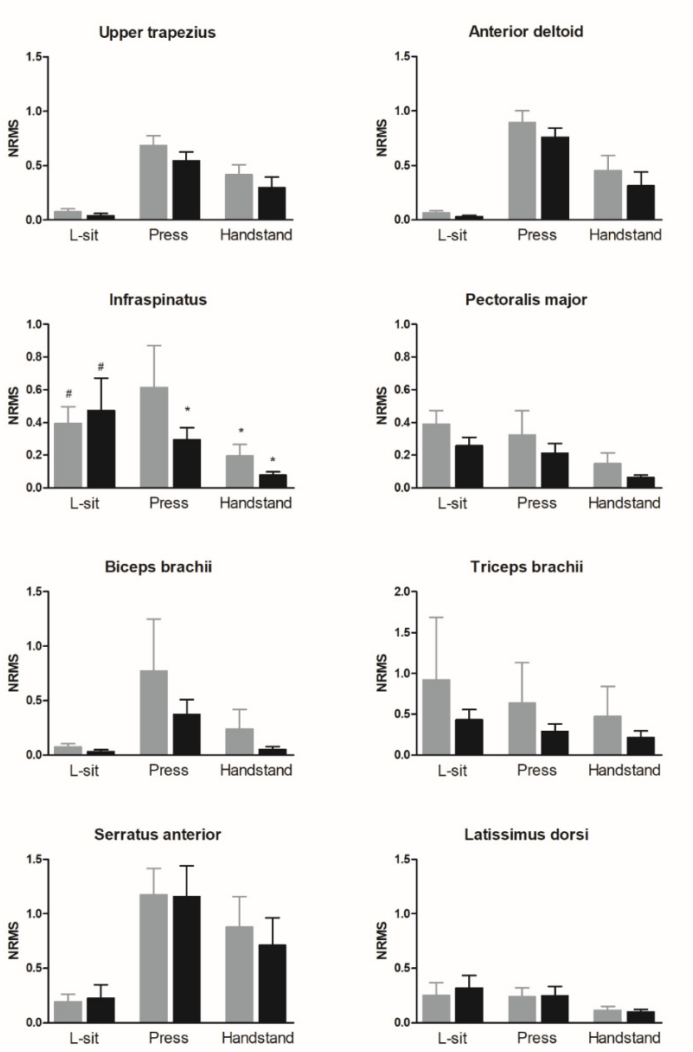


**Figure 2.** Mean normalized electromyographic root mean square (NRMS) values during the press handstand on parallel bars.
*Bars and whiskers represent mean ± 95% confidence intervals, respectively. Grey bars: young gymnasts; black bars: adult gymnasts. Significant difference * vs. young gymnasts during the press phase; # vs. adult gymnasts during the handstand phase at $p \leq 0.05$*

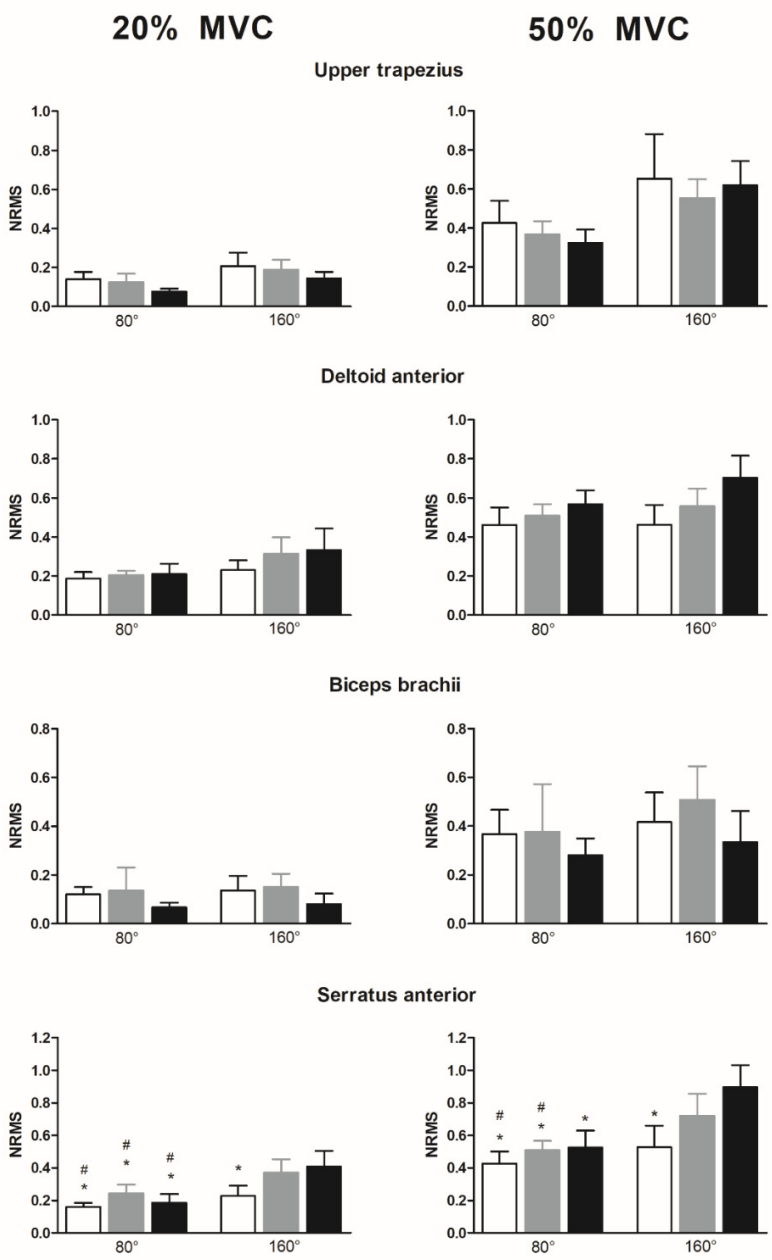


**Figure 3.** Mean normalized electromyographic root mean square (NRMS) values of agonistic muscles during submaximal isometric muscle contraction (flexion) in the position of 80° and 160° of the shoulder joint complex.

*Bars and whiskers represent mean ± 95% confidence intervals, respectively. MVC: maximal voluntary contraction. White bars: young gymnasts unable to perform the press handstand; grey bars: young gymnasts capable of performing the press handstand; black bars: adult gymnasts. Significant difference * vs. adult gymnasts in the position of 160° in the shoulder joint complex; # vs. young gymnasts capable of performing the press handstand in the position of 160° in the shoulder joint complex at $p \leq 0.05$*

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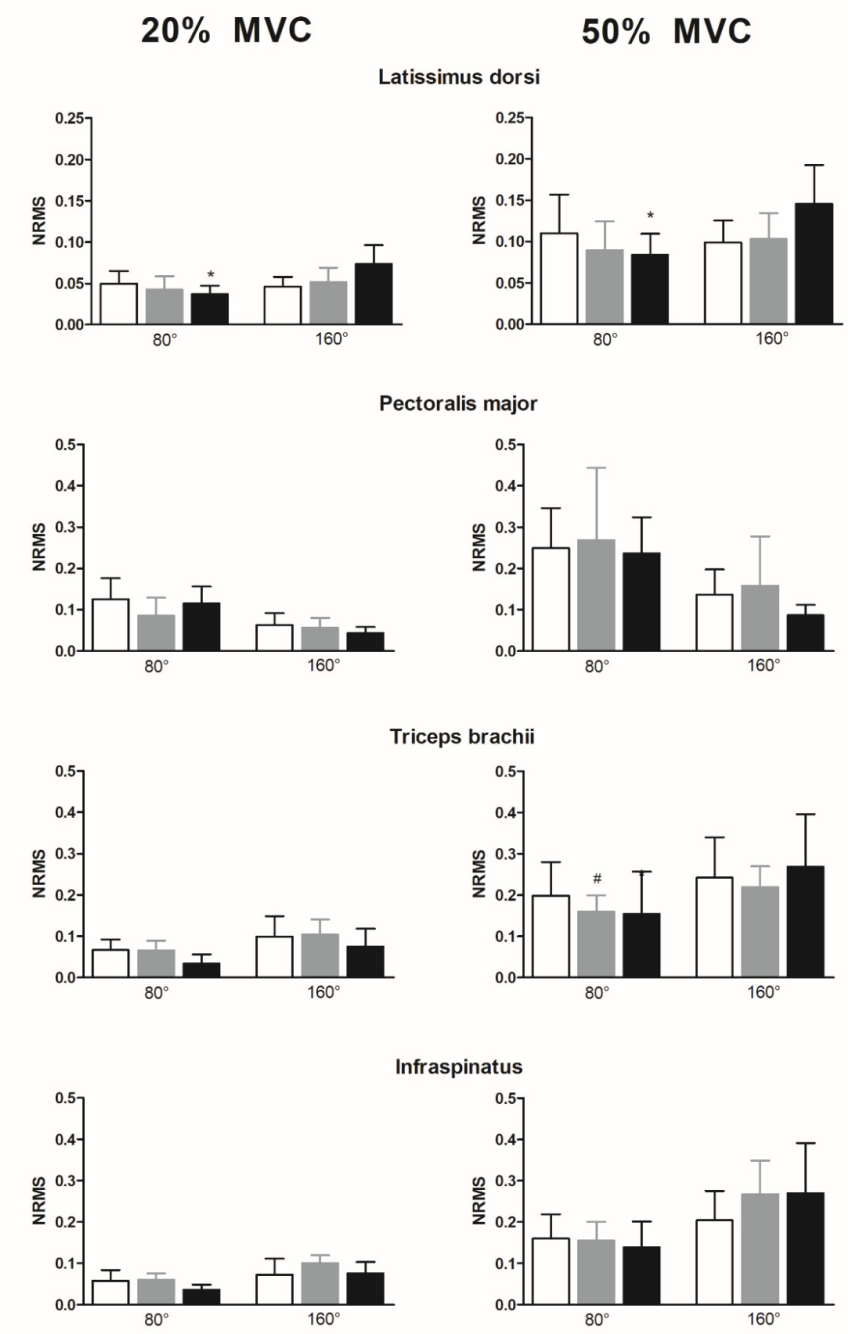


**Figure 4.** Mean normalized electromyographic root mean square (NRMS) values of antagonistic muscles during submaximal isometric muscle contraction (flexion) in the position of 80° and 160° of the shoulder joint complex.

*Bars and whiskers represent mean ± 95% confidence intervals, respectively. MVC: maximal voluntary contraction. White bars: young gymnasts unable to perform the press handstand; grey bars: young gymnasts capable of performing the press handstand; black bars: adult gymnasts. Significant difference * vs. adult gymnasts in the position of 160° in the shoulder joint complex; # vs. young gymnasts capable of performing the press handstand in the position of 160° in the shoulder joint complex at $p \leq 0.05$*

## Discussion

The first aim of the study was to compare muscle activation during the PHPB within YGs and AGs. YGs, as less experienced, appeared to struggle with performing the PHPB to a great extent in comparison with AGs. It was reflected by higher muscle activity in all investigated agonistic muscles (UT, DA, BB) except the SA muscle, of which activity was at a similar level in YGs and AGs. With regard to antagonistic muscles, only PM and IS muscles presented an increased activity in YGs, probably indicating a higher need for stabilizing the shoulder joint complex. It was especially seen during the press phase of the PHPB in the IS muscle, where YGs had two times higher muscle activity as compared with AGs. The observed higher level of muscle activity in YGs than in AGs is consistent with the fact that the muscle activity of the same submaximal task decreases across the ontogenetic development in children (Dotan et al., 2012; Woods et al., 2024), but also owing to training as it enhances neuromuscular efficiency (Felici, 2006; Milosis et al., 2023 Prończuk et al., 2025). The same was reported previously, when younger gymnasts (8–10 years old) exhibited higher muscle activation of lower limbs during landings in comparison with older ones (12–14 years old) and adults (Niespodziński et al., 2021), as well as during the handstand between YGs and AGs (Kochanowicz et al., 2018, 2019). Dotan et al. (2012) inferred that decreased muscle activation in AGs could be explained by increased capability of recruiting higher threshold type II motor units in terms of nervous system maturation both on the ontogenetic and sport training background (Dotan et al., 2013). The muscle activation differences between YGs and AGs observed during the PBPH were also noticed in neuromuscular efficiency tasks, where UT and BB muscles showed lower activity in AGs as compared with YGs.

Not all YGs at a mean age of 11 years old are capable to perform the PHPB. Therefore, the second aim of the study was to compare neuromuscular performance of AGs and YGs-C with that of YGs-N.

The first phase (L-sit) is the easiest part of the PHPB; all investigated YGs were able to perform this part. Here, the main muscles involved are the abdominal muscles and hip joint flexors. However, the current study showed that also the TB, PM, IS, and LD muscles increased their activity in this phase as compared with the remaining participants. During the L-sit, the TB locks the elbow joint in an extended position. In turn, the PM, IS, and LD muscles stabilize the shoulder joint complex to maintain a still position against torque that is developed by the centre of mass, localized forward because of the horizontal position of the lower limbs. The last phase (handstand), more demanding than the L-sit, can be performed by most YGs when it is undertaken alone, especially on parallel bars. This is due to the fact that the range of motion in radiocarpal joints is limited by the grip and it is easier for YGs to control the handstand position using more proximal joint strategies, i.e., shoulder and hip joints, but in expense of the overall quality of the performance (Kochanowicz et al., 2019). In this phase, the UT, DA, and SA muscles showed relatively high activity as compared with other phases. This is because UT and SA muscles must maintain the shoulder joint complex in continuous elevation against the body weight, while the DA is the main muscle utilizing the shoulder strategy of balance control in the inverted position (Kochanowicz et al., 2019). On the other hand, LD, PM, and especially IS muscles exhibited the lowest activity; the reason is that their torque producing capabilities coincide with the gravitational torque, which gymnasts fight against to maintain balance (LD, PM) or of which rotational potential is limited owing to the restricted plane of motion on parallel bars (IS).

While the L-sit and handstand phases of the exercise are relatively easy for all YGs (Kochanowicz et al., 2015), in the press phase, some of them encounter insurmountable difficulties. The press phase of the PHPB is considered to be mostly dependent on muscle strength of shoulder joint complex flexors and hip joint flexibility (Prassas, 1988). In the mentioned study, gymnasts performed the straddled leg variation of the PHPB, in which the limited range of motion of hip joints played a minor role (Prassas et al., 1986). Thus, the reason of not performing the PHPB should lie within aspects of muscle strength and/or neuromuscular control. This was in line with the current study, where UT, DA, BB, and SA muscles showed the highest muscle activity as compared with other phases. Considering shoulder joint

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complex flexor peak torque normalized to body mass, there were no differences between YGs-C and YGs-N. The same lack of difference among YGs was observed for muscle activity in 20% and 50% MVC tasks, unless evaluated in the position of 160° in the shoulder joint complex. In 160° of the shoulder joint complex, it was found that YGs-N presented much lower muscle activity of the SA than their more skilled peers and AGs. This suggests that YGs-N have difficulties to utilize proper neuromuscular control within muscles acting at the acromioclavicular and sternoclavicular joints rather than the glenohumeral joint. This is consistent with our observation of YGs-N that attempted to perform the PHPB (results not presented), where they failed to complete the exercise mostly during the phase of raising the trunk above the horizontal level (flexion of 80–110° in the shoulder joint complex) in the press phase.

The shoulder joint complex consists of three anatomical joints: glenohumeral, acromioclavicular, and sternoclavicular. The first one is responsible for the movement of the humerus relative to the scapula up to about 115° of flexion in specific trained individuals like acrobats (Huberman et al., 2020). The two others, while also participating in the humerus movement (Teece et al., 2008; Zhu et al., 2024), are mainly responsible for elevating the arm above the head. In the current study, arm elevation to 160° of flexion in the shoulder joint complex during neuromuscular performance tasks increased the muscle activity of all investigated muscles except the PM. These results are consistent with sitting military press research, where exercise utilizing a broader abduction range of motion in the shoulder joint complex, i.e., 180° and 135°, elicited higher muscle activation as compared with 90° in both, muscles acting only at the glenohumeral joint and also the acromioclavicular and sternoclavicular joints (Paoli et al., 2010). The increased muscle activation in the SA and the UT could be explained by their main function in elevating the arm but also by a reduction in muscle length in 160° of flexion. It was previously reported that reproducing the same torque under shorter muscle length conditions resulted in higher muscle activity (Mohamed et al., 2002). Considering DA and BB muscles, it could be explained not only by muscle shortening (as the 80° position is, typically for gymnasts, below a limit range of motion of the glenohumeral joint), but also by the fact that these muscles act solely at the glenohumeral joint, and when the arm is elevated, they must contract to generate target torque, as well as to maintain the glenohumeral in maximal flexion. A similar outcome was observed previously, where the BB muscle gradually increased its activity in 45°, 90°, and 135° of flexion in shoulder complex joints during a 30% MVC task (Sakurai et al., 1998). Interestingly, in the current study, only the 50% MVC task brought about the same results. Probably, the 20% MVC task provided too little load to elicit those differences in SEMG activity. Moreover, in the current study, MVC was performed at 80°, while Sakurai et al. (1998) used a position of 45°. A similar increase in muscle activity in the position of 160° flexion was observed in antagonistic muscles: LD, TB, and IS. While in the IS, the increase was reported in all groups, in LD and TB muscles, the increase was limited only to AGs or both groups that were capable of performing the PHPB, respectively. This suggests that the increased activation of agonistic muscles was counterbalanced by an increase in the activation of the antagonistic muscle to maintain proper shoulder complex joint stabilization (Milosis et al., 2023; Veeger and van der Helm, 2007). Of interest, the muscle activity of the PM, contrary to other antagonistic muscles, decreased in the position of 160° of flexion. This could be due to the fact that the PM does not act as a typical antagonistic muscle. Its antagonistic function is possible only when the arm is elevated; otherwise, it is mainly a glenohumeral joint flexor and adductor (Wickham and Brown, 2012). It is likely that during MVC testing and further neuromuscular assessment performed in the 80° position, there was some crosstalk from PM muscle fibers that generate some flexion torque, especially from the clavicular part (Arwert et al., 1997; Lee, 2019; Lulic-Kuryllo et al., 2021), and when the arm was elevated up to 160°, overall fewer motor units were active, mainly in the antagonistic contraction (Illyes et al., 2009; Owens et al., 2024).

The SA muscle plays a particular role in this motion as it is the main muscle responsible for the upward/lateral rotation of the scapula. The lower muscle activity of the SA in YGs-N and its similar activation level in YGs-C in comparison with AGs during the PHPB suggest that neuromuscular control involving the SA muscle

seems to be crucial in PHPB performance of YGs struggling with this exercise. The SA is not the only muscle responsible for the upward/lateral rotation of the scapula. The other muscle of much importance in this role is the UT (Owens et al., 2024). While there were no significant differences between the groups in neuromuscular efficiency during the position of 160° of flexion in the shoulder joint complex, it was observed that YGs-N presented the highest muscle activation of the UT among all groups. Perhaps, the lack of adequate SA activation was compensated by increased UT activity. On the other hand, the DA muscle exhibited lower activation, similar to the SA, in YGs-N in comparison with AGs. It is possible that YGs-N also had problems in adequate DA activation that provides stable maximal flexion position of the glenohumeral joint, and thus forces different intermuscular coordination. There is a need to further investigate these differences and developmental changes of the DA, SA, and UT muscle coordination in gymnasts.

Future studies should also investigate whether the observed differences in neuromuscular coordination are relevant to exercises performed on other apparatuses, particularly during the press to handstand on still rings, where the same movement is executed under conditions of reduced support stability (Mendez-Rebolledo et al., 2022) and may pose a challenge even for adult gymnasts.

### *Limitations*

One of the study limitations is that, while we observed difference in muscle activity in 80° and 160° of the shoulder joint complex, we cannot fully relate that to muscle strength in terms of torque production as MVC was performed only in the position of 80° (Skalski et al., 2025). It is possible that in the position of 160°, YGs-N and YGs-C would show differences in peak torque production, which was not observed at 80°. Nevertheless, the current study indicated which specific muscle (SA) could be partially responsible for difficulties in the PHPB performance and described MVC evaluation provides additional proof confirming this outcome. Another limitation of the study is that no SEMG signals from muscles responsible for downward scapula rotation were evaluated. The outcomes of the study showed that muscles controlling the scapula movement in the acromioclavicular joint could be crucial for PHPB performance. The main muscles responsible for downward rotation are the rhomboid muscles, however, recording the SEMG signal from them is rather limited as they are hidden underneath the trapezius muscle (Castelein et al., 2016 ; Skalski et al., 2025). Thus only fine wire EMG recordings could provide signals from rhomboid muscles without excessive cross-talk, which was beyond our evaluation. Lastly, the study focused solely on muscle activity, and no data regarding kinematics or dynamics during the PHPB were presented. While such information would enhance understanding of the biomechanics of performing the PHPB in YGs-C, it would not provide additional insight for YGs-N, who were evaluated only under laboratory conditions. Therefore, this aspect was beyond the scope of the study.

### *Practical Implications*

The results of this study offer insights for gymnastics coaches, physiotherapists, and athletic trainers working with YGs. The observed elevated muscle activity in less experienced gymnasts during the PHPB highlights the importance of neuromuscular efficiency and scapular control in the successful execution of this complex skill. Specifically, the SA muscle appears to play a critical role in performance, as its activation level distinguished gymnasts capable of executing the PHPB from those who were not. Given that the SA, along with DA and UT muscles, is key to stabilizing the shoulder joint complex (Walker et al., 2023), particularly in high degrees of flexion, targeted strengthening and motor control training of these muscles should be emphasized in gymnast conditioning programs. Moreover, since YGs-N tend to compensate for poor SA activation with increased UT activation, this imbalance could lead to inefficient movement patterns and potentially increased injury risk. Therefore, coaches should implement specific exercises aimed at improving scapular stability, such as closed-chain (elastic banded) punches, push-up plus, wall slides, or high-range overhead pressing.

## Conclusions

All investigated muscles exhibited increased activity in YGs during the PHPB, except the SA muscle. The muscle activity of the SA seems to be crucial in PHPB performance for YGs

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struggling with this exercise, as the SA was the only muscle with a similar level of activity in this group as in AGs during the PHPB and the only muscle that showed differences in neuromuscular efficiency between YGs-C and YGs-N. The evaluation of gymnasts' shoulder joint complex should always consider assessment including a high degree of flexion (in the second half of the range of motion) to investigate muscles related not only to the glenohumeral joint, but also to the acromioclavicular and sternoclavicular joints.

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***Informed Consent:*** Informed consent was obtained from all participants included in the study.

***Conflicts of Interest:*** The authors declare no conflict of interest.

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