Changes in the Muscle Activity of Gymnasts During a Handstand on Various Apparatus

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Abstract

Kochanowicz, A, Niespodziński, B, Mieszkowski, J, Marina, M, Kochanowicz, K, and Zasada, M. Changes in the muscle activity of gymnasts during a handstand on various apparatus. *J Strength Cond Res* 33(6): 1609–1618, 2019—Gymnasts perform handstands on various apparatus, both in stable and unstable conditions. Such performances require specific muscle activation, which should differ depending on the condition and expertise of the gymnast. Therefore, the aim of the study was to evaluate (a) the difference in electromyography (EMG) between handstands performed on 3 apparatus (floor, rings, and parallel bars); and (b) the difference between young and well-trained adult gymnasts. Ten adult (25 ± 3.94 years) and 15 young (13.9 ± 0.7 years) gymnasts participated in the study. We investigated EMG amplitude in 13 muscles normalized by arbitrary angle maximal isometric voluntary contraction (normalized root mean square [NRMS]). In comparison with the handstand on the floor (61 ± 28%), the wrist flexor muscles of gymnasts exhibited a decreased NRMS on the parallel bars (44 ± 25%; $p = 0.017$), and rings (46 ± 32%; $p = 0.029$), whereas no changes were observed in the triceps brachii. The rest of the investigated muscles showed a higher NRMS in rings. Differences between young and adult gymnasts were seen in the triceps brachii and anterior deltoid muscles, where more experienced gymnasts showed 19.1% ($p = 0.014$) and 17.6% ($p = 0.048$) lower NRMS, respectively. The different gymnastic apparatus led to specific muscle activation. This activation predominantly depended on hand support conditions, which alternated the primary wrist strategy of the handstand balance control, and in consequence, the activation of other muscles controlling balance. Training focused on the development of motor control and strength of the anterior deltoid, pectoralis major, latissimus dorsi, biceps brachii, and trapezius descendens muscles to improve handstand performance.

Key Words gymnastics, surface electromyography, postural control, inverted stance

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Introduction

The handstand is one of the primary gymnastic skills, which is necessary to achieve to obtain other more difficult and complex skills (19,27). Although the handstand on a stable surface (e.g., floor or parallel bars) is fairly simple for a gymnast to perform, on still rings, this is a demanding task even for experienced gymnasts (32). Maintaining a handstand in such an unstable condition requires many years of training to develop the necessary sense of balance that is achieved by exercises that stimulate proprioceptive, vestibular, and visual sensors (15,33,36).

Young gymnasts (YG) start performing handstands on a flat surface such as the floor after 3–4 years of training, typically at the age of 7–11 years (22). To advance and improve the handstand, gymnasts need to progress onto apparatus that requires a handgrip, such as parallel bars. In such conditions, the base of support is still stable, although a change in the position of the wrist joint may alter the strategy of maintaining a handstand. The most difficult condition for a handstand in an all-around gymnastics competition for men is the still rings. Although the handgrip on still rings is similar to the one on parallel bars, the still rings provide an unstable base of support, which requires a more highly trained sense of proprioception (39).

In the literature, there are examples of biomechanical analyses of the handstand including analyses of postural control (2,9,36) and dynamics analysis (16,21,35), but evaluation of muscle activity in either stable or unstable conditions has not been comprehensively described (3,39). Such evaluation can be helpful when depicting the involvement of an individual muscle in various handstand conditions. Insight into the muscle activity changes observed in athletes associated with increased exercise difficulty gives direct information about which muscles should be specifically conditioned to improve performance.

This study hypothesizes that the different handgrips adopted for each apparatus should modify the muscle activity and coactivation levels of the upper-limb muscles. The reason for this may lie in an alteration of the balance control strategy. This is primarily managed by the wrist joints, and supported by the shoulder and hip joints, which are more in demand when the wrist control strategy is insufficient (21,40). As the unstable conditions of still rings are comparable with suspended pendulums, more alternations in handstand balance strategies should occur. In such conditions, when gymnasts produce force on still rings, they cannot act as a fixed support for the wrist movement and they move in the direction of the applied force (39). This should result in an increase in the muscle electromyographic (EMG) signal, especially in the shoulder and the elbow joints. The specific increase of the EMG signal in the parallel bars and still rings indicates which muscles are primarily involved in the exercise, and therefore gives vital information that could be used in case of difficulty performing a handstand correctly on these apparatus. Gymnasts train during the early years of their physical development and later on during the master stage, their ability to control balance in the upright and inverted positions increases continuously (2,9,17). This study's second hypothesis is that the EMG signal during a handstand on various apparatus will show a difference in the magnitude of muscle activity between YG and adult gymnasts (AG) (6). Knowing that systematic training changes the flexor/extensor strength ratio in the shoulder joint of YG (26), it has been hypothesized that balance control strategy, which affects the pattern of muscle activity, should also change throughout the gymnastic lifespan. Thus, YG, who have not yet mastered the handstand, might show a different pattern of muscle activation when they are confronted with more difficult conditions. Knowing these changes in muscle activation can be very beneficial when creating physical conditioning programs that target these primary muscles in YG practicing handstands on these apparatus.

Therefore, the aim of this study was to describe differences in the surface EMG signal of gymnasts' muscles during a handstand on various apparatus and to assess the differences between YG and their well-trained adult peers.

Methods

Experimental Approach to the Problem

Authors used an experimental investigation with cross-sectional study design to evaluate muscle activity differences during a handstand performed on 3 apparatus: floor, rings, and parallel bars, by both YG and AG. In this study, muscle activity served as the dependent variable, and different apparatus and age groups as the independent variable.

Subjects

Ten male AG (21–31 years old) and 15 male YG (12.3–15 years old) participated in the study. The characteristics of the participants are described in Table 1.

Each gymnast started his training career at the early age of 6 or 7 years. YG were prospective athletes that had acquired the ability to perform a stable handstand on the floor and parallel bars, but a handstand on still rings was a difficult task for them and was performed with visible effort. Two of them were able to perform a handstand on the floor only. AG were elite gymnasts who could perform a stable handstand in various conditions, including still rings. All athletes were in a competitive training phase (October) and had no history of injuries or neuromuscular disorders in the past 2 years. Each participant was well hydrated during the measures, which were taken 2 to 3 hours after their first meal in the morning.

The study was conducted according to the Declaration of Helsinki and with an approval of the Bioethics Committee at the Regional Medical Chamber in Gdansk with approval number of KG -12/15. All participants and legal guardians gave informed written consent and were informed of the risks and benefits of the study.

Procedures

The study consisted of 2 parts. First, after a basic physical characteristics evaluation in the laboratory, athletes performed maximal voluntary contractions (MVCs) in the laboratory for EMG normalization purposes. Second, each gymnast performed a handstand in various conditions (apparatus) in their regular gymnastic training gym. Before each measure, the gymnasts performed an individual 15-minute warm-up routine at the training gym.

In the first part, the MVC measures were performed on a Biodex System 4 dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA) and by manually testing in selected positions. After a practice session, each participant performed three 4-second repetitions in each evaluated joint. On the dynamometer, all settings and measures were performed according to manufacturer's guidelines (25): (a) shoulder joint in the position of 90° flexion (Figure 1A); (b) shoulder joint in the position of 90° abduction (Figure 1B); (c) elbow joint in the position of 90° flexion with 45° of shoulder joint (Figure 1C); (d) knee joint in the position of 90° flexion, with 90° flexion of the hip joints (Figure 1D); and, (e) wrist joint in the neutral position between flexion and extension, with 90° flexion of the elbow joint (Figure 1E). The position of each gymnast was stabilized either manually or using leather straps. During shoulder measurements, an additional elbow orthosis was also used.

Normalization for the multifidus, gluteus maximus, and rectus abdominis muscles was performed manually

Table 1. Characteristics of the 2 groups of male participants.

	Young gymnasts ($n = 15$)	Adult gymnasts ($n = 10$)
	Mean ± *SD*	Mean ± *SD*
Age (y)	13.9 ± 0.7	25 ± 3.94
Mass (kg)	45.2 ± 7.7	71.5 ± 2.99
Height (cm)	154.9 ± 9.8	172.3 ± 4.3
Training experience (y)	7.7 ± 0.8	17.8 ± 2.8
Training routine ($h \cdot wk^{-1}$)	22	24

according to positions described by other authors: gluteus maximus with the hip joint at 0° (38) (Figure 2A); multifidus with upper-trunk extension (Figure 2B); and flexion for rectus abdominis (37) (Figure 2C). Between each attempt with a dynamometer or by manual measurement, gymnasts had a 1-minute rest period to reduce the fatigue effect and were verbally encouraged to maximize their effort. Each participant was familiarized with the study protocol a day before the measurements were taken.

In the second part, gymnasts performed a 5-second handstand in 3 conditions: on the floor, on the parallel bars, and on the still rings, in random order. Each handstand was rated by 2 domestic level judges who were observing proper performance of the skill. The proper handstand was understood as a flawless performance by AG in terms of regulation of the Code of Points under the International Gymnastic Federation (FIG) (13). For YG, small faults were permitted (0.1 point by FIG) during the handstand, such as a 15° leg deviation from the frontal plane made by arms and torso. Hand placement on the floor and the inner edge of parallel bars were set at the gymnast's shoulder width. The gymnast performed a handstand on parallel bars with each hand on a separate bar. All apparatus met the requirements of FIG (13) In each condition, gymnasts did at least 3 trials of the handstand, and unless 3 of them were performed in a proper way, more attempts were performed. Between each trial, a 1-minute rest period was allowed, and the 3 best attempts were taken into consideration for analysis.

Figure 1. The setup and positions of gymnasts during recording of a maximal voluntary contraction at arbitrary angles that were used for electromyographic normalization. A) Shoulder joint (sagittal plane)–anterior deltoid (flexion), pectoralis major, and the latissimus dorsi (extension); (B) shoulder joint (frontal plane)–trapezius descendens and the lateral deltoid muscles (abduction); (C) elbow joint–biceps and the triceps brachii (flexion and extension, respectively); (D) knee joint–rectus femoris (extension); (E) wrist joint–wrist flexors and extensors.

Electromyography. Before data collection, each participant's skin was prepared for surface EMG evaluation according to the SENIAM organization (20), including scrubbing, cleaning with alcohol, and shaving, if necessary. Placement of electrodes was consistent with SENIAM (20) and Cram's Introduction to Surface Electromyography guidelines (8). Thirteen muscles were investigated: trapezius descendens, latissimus dorsi, lateral deltoid, anterior deltoid, triceps brachii, biceps brachii, wrist extensors, wrist flexors, pectoralis major (pars sternalis), multifidus, gluteus maximus, rectus abdominis, and rectus femoris. Electrodes were placed on muscles on the dominant side of the body, specified by the hand used for writing. As selective EMG signals from the forearm muscle are difficult to obtain without crosstalk between one and another (24,28), the above described electrode placement for wrist joint muscles was considered as a group of functional flexors and extensors of the wrist joint. This was considered sufficient for the purpose of this study.

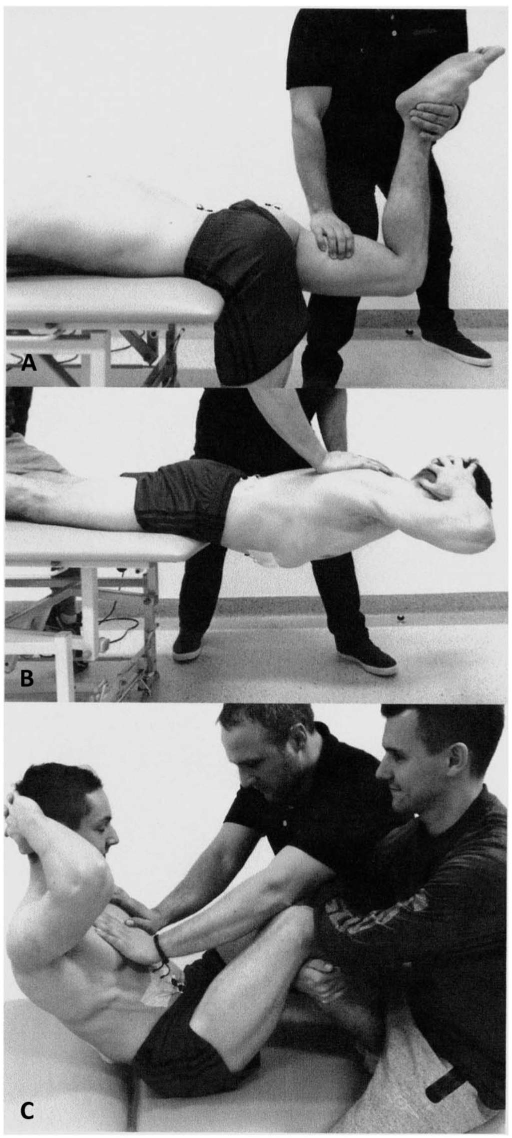

Figure 2. The positions of gymnasts during recordings of muscle activity during manually applied resistance, which were used for electromyographic normalization. A) Gluteus maximus, (B) multifidus, (C) rectus abdominis.

The EMG signals were gathered using Ag/AgCl electrodes (1 cm^2 of active area–Sorimex, Toruń, Poland), with an interelectrode distance of 20 mm, and recorded by Noraxon's (Scottsdale, AZ, USA) TeleMyo DTS EMG system with a sampling rate of 1,500 Hz and a 10–500 Hz bandpass filter. The electromyograph had an input impedance of above 100 MΩ, a base gain of 500, and a Common Mode of Rejection which was above 100 dB. The raw data were stored with Noraxon's MyoResearch 1.08 software (Scottsdale, AZ, USA) and subsequently processed. The EMG data were fully rectified and smoothed by calculating the root mean square (RMS, μV) values using 50 ms time frames. Finally, to reduce interindividual variability, RMS was normalized to the signal recorded during an arbitrary angle maximal isometric voluntary contraction. This was calculated as the peak value recorded during a 1-second time frame taken from the middle 2 seconds of the performance. Normalized RMS (NRMS) was expressed as a percentage (5). To reduce the intraindividual variability of EMG signals, results were calculated as the mean value of 3 handstand attempts. Reliability of the surface EMG measures was extensively studied (1,7,23), and, depending on the investigated muscle, was found to be good to excellent in stable and unstable conditions (10).

Statistical Analyses

To assess the significance of the differences observed between EMG signals in the 3 conditions (floor, parallel bars, and still rings) and between AG and YG, a 2-way (2 groups × 3 apparatus) analysis of variance of repeated measures was performed. The 3 conditions (floor, parallel bars, and still rings) were considered as the "within subject factor," also called the repeated measure factor (apparatus). The expertise (young versus adults) served as the "between subject factor" (group). If an interaction was significant, simple main effect analysis was conducted. Post hoc analyses were implemented when appropriate with Tukey's post hoc test with amendment for different sized groups. Shapiro-Wilk and Levene's tests were performed to check the normal distribution and the homogeneity of variance, respectively. In addition, the effect size of each factor was calculated using the partial Eta-squared (η^2) statistic. If the particular result of individual exceeded 3 *SDs*, it was excluded from the analysis. An effect was considered statistically significant when $p \leq 0.05$. All analyses and graphs were performed with the commercial software Statistica 10 (Statsoft Inc., Tulsa, OK, USA).

Results

Figure 3 depicts muscles whose NRMS values surpassed 30% MVC condition (mainly the upper-body muscles), whereas Figure 4 depicts muscles that did not reach the threshold of 30%. The arbitrary threshold of 30% of NRMS was chosen to show results in a clear way on the same axis, with the same scale, in each graph. All analyses below are shown for each

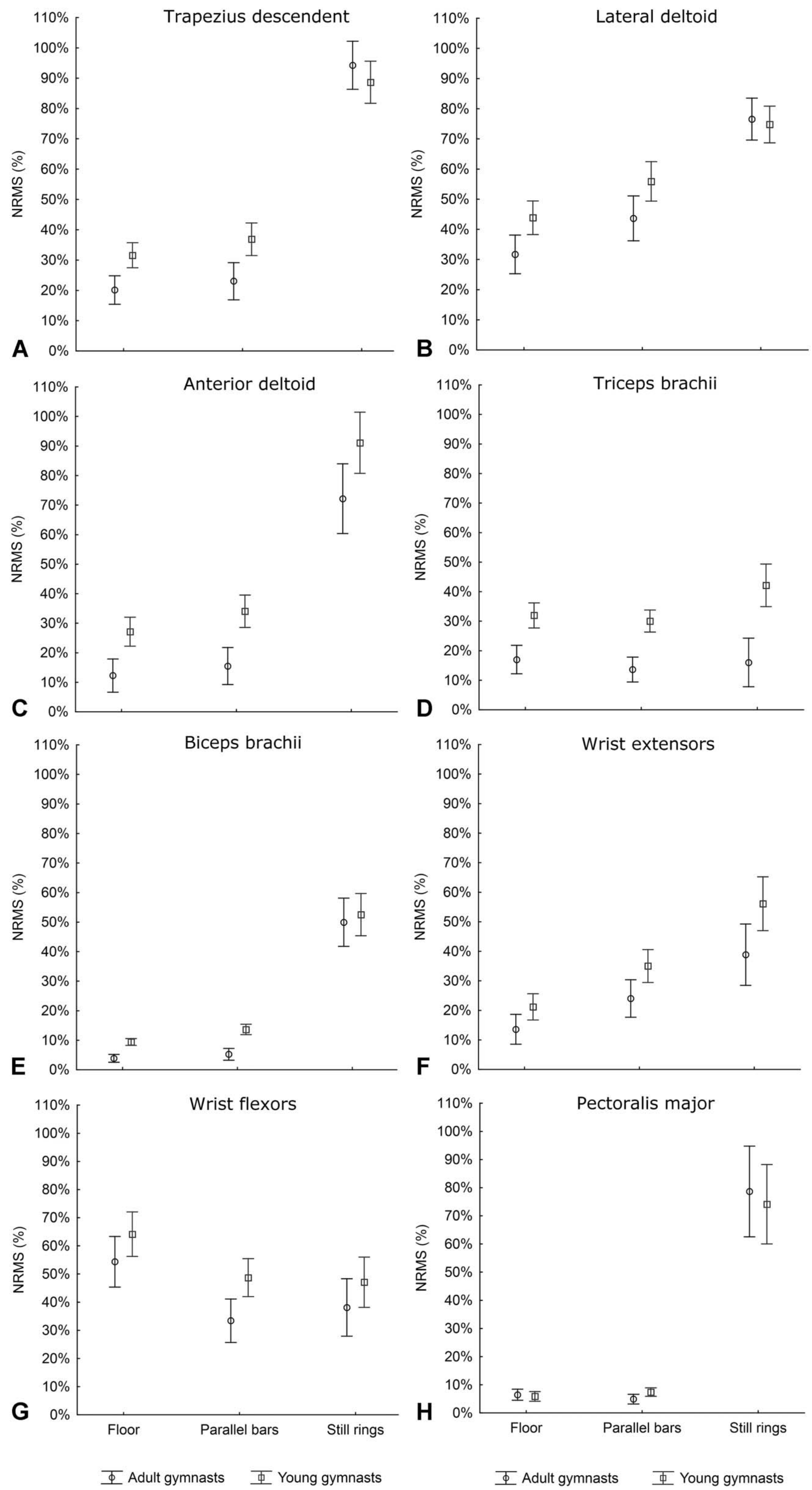

Figure 3. Normalization of the root mean square values, expressed as a percentage with respect to the maximal voluntary contraction (MVC) condition. Representation of the muscles with electromyographic signals above 30% of MVC. Whiskers represent the *SEs*.

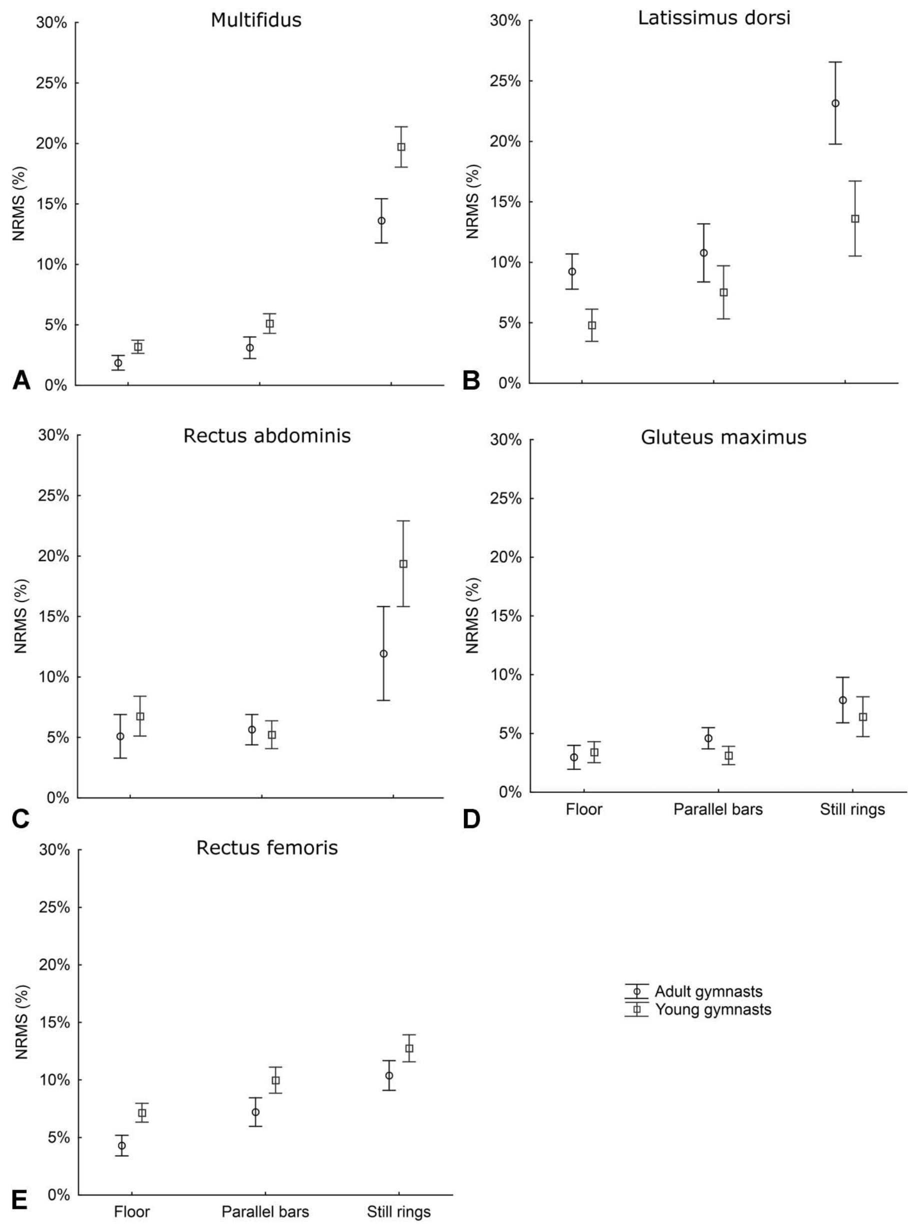

Figure 4. Normalization of the root mean square values, expressed as a percentage with respect to the maximal voluntary contraction (MVC) condition. Representation of the muscles with electromyographic signals below 30% of MVC. Whiskers represent the *SEs*.

muscle individually. Detailed statistical results are presented in Table 2.

The trapezius descendens (Figure 3A) was the only muscle that showed a significant apparatus per group interaction (Table 2). Post hoc analysis to compare the apparatus between both groups demonstrated an increased percentage NRMS for rings in comparison with the other 2 apparatus (100% of the sample). There were no differences observed between adult experts and their young peers on each individual apparatus (Table 2). In the lateral deltoid muscle (Figure 3B), a significant effect of the apparatus ($p \leq 0.001$) was demonstrated by successive NRMS increments from the floor, to the parallel bars, to the rings (83% of the sample). No differences were observed between the 2 groups (Table 2). The anterior part of the deltoid muscle (Figure 3C) showed 2 simple main effects. The NRMS of the rings was increased in comparison with the other 2 apparatus (96% of the sample), and YG had significantly higher values of NRMS than AG (Table 2). The triceps brachii muscle (Figure 3D) showed a significant effect of

TABLE 2. Analysis of the normalized root mean square when performing a handstand in different conditions: 2 groups × 3 apparatus, analysis of variance of repeated measures.*

Muscle	Effect	*F*	*df*	*p*	Effect size (partial η^2)	Post hoc	*p*
Trapezius descendens	Ap × Gr	3.59	2, 42	0.036	0.14	AG, YG: R > B, F	≤0.001
	Ap	172.32	1, 21	≤0.001	0.89	R > B, F	≤0.001
	Gr	0.07	1, 21	0.369	0.04		
Lateral deltoid	Ap × Gr	1.95	2, 42	0.155	0.09		
	Ap	45.08	1, 21	≤0.001	0.68	R > B > F	0.013
	Gr	0.9	1, 21	0.353	0.04		
Anterior deltoid	Ap × Gr	0.06	2, 42	0.94	≤0.01		
	Ap	57.54	1, 21	≤0.001	0.73	R > B, F	≤0.001
	Gr	4.39	1, 21	0.048	0.17	AG < YG	0.048
Triceps brachii	Ap × Gr	1.21	2, 42	0.307	0.05		
	Ap	1.77	1, 21	0.183	0.08		
	Gr	8.38	1, 21	0.008	0.29	AG < YG	0.013
Biceps brachii	Ap × Gr	0.23	2, 42	0.795	0.01		
	Ap	67.88	1, 21	≤0.001	0.76	R > B, F	≤0.001
	Gr	1.67	1, 21	0.21	0.07		
Wrist extensors	Ap × Gr	0.80	2, 42	0.452	0.04		
	Ap	30.84	1, 21	≤0.001	0.59	R > B > F	0.007
	Gr	1.73	1, 21	0.203	0.08		
Wrist flexors	Ap × Gr	0.2	2, 42	0.819	0.01		
	Ap	6.88	1, 21	0.003	0.25	R, B < F	0.006
	Gr	1.23	1, 21	0.281	0.06		
Pectoralis major	Ap × Gr	0.09	2, 42	0.914	≤0.01		
	Ap	47.06	1, 21	≤0.001	0.69	R > B, F	≤0.001
	Gr	0.01	1, 21	0.914	≤0.01		
Multifidus	Ap × Gr	3.11	2, 40	0.055	0.13		
	Ap	111.42	1, 20	≤0.001	0.85	R > B, F	≤0.001
	Gr	7.57	1, 20	0.012	0.23	AG < YG	0.027
Latissimus dorsi	Ap × Gr	1.88	2, 40	0.164	0.08		
	Ap	24.74	1, 20	≤0.001	0.55	R > B, F	≤0.001
	Gr	4.18	1, 20	0.054	0.17		
Rectus abdominis	Ap × Gr	1.89	2, 40	0.164	0.08		
	Ap	15.17	1, 20	≤0.001	0.43	R > B, F	0.002
	Gr	1.32	1, 20	0.264	0.06		
Gluteus maximus	Ap × Gr	0.43	2, 42	0.651	0.02		
	Ap	6.51	1, 21	0.003	0.24	R > B, F	0.019
	Gr	0.45	1, 21	0.509	0.02		
Rectus femoris	Ap × Gr	0.05	2, 40	0.949	≤0.01		
	Ap	26.23	1, 20	≤0.001	0.57	R > B > F	0.002
	Gr	4.51	1, 20	0.046	0.18	AG < YG	0.056

*Ap = apparatus; Gr = group; R = rings; B = parallel bars; F = floor; AG = adult gymnasts; YG = young gymnasts.

the group. No differences were found among the 3 apparatus (Table 2). The biceps brachii (Figure 3E) showed a significant effect of the apparatus, with higher NRMS in rings (96% of the sample), but not of the group (Table 2). Wrist extensors (Figure 3F) showed a similar outcome to the lateral deltoid; from the highest NRMS values from the rings, to the parallel bars, to the lowest NRMS values from the floor, regardless of the group (87% of the sample). Wrist flexors (Figure 3G) were the only muscles that showed a significant effect of the apparatus ($F(2,42) = 6.87$, $p = 0.003$; Table 2), where the activity on the floor (60 ± 28%) was higher in comparison with parallel bars (42 ± 25%) and still rings (43 ± 32%) (70% of the sample). There were no differences between adults and their young peers on each individual apparatus. The last of the muscles that reached NRMS values above the threshold of 30% MVC was the pectoralis major (Figure 3H). Similar to most of the investigated muscles, regardless of the group, the higher NRMS values were recorded on still rings in comparison with the floor and parallel bars (100% of the sample) (Table 2). It should be noted that the NRMS of the floor and parallel bars was substantially lower than the one recorded on the rings. Moreover, the data collected on the rings showed a high level of variability of the EMG signal (±50%).

When analyzing muscles where NRMS did not exceed 30% MVC, the multifidus muscle (Figure 4A) activity was significantly higher in rings than in the other 2 apparatus (100% of the sample). Moreover, the group effects confirmed that NRMS values were significantly lower in AG compared with YG. The latissimus dorsi (Figure 4B), the rectus abdominis (Figure 4C), and gluteus maximus (Figure 4D) had a similar statistical outcome. That is, regardless of expertise level (absence of the group effect), the NRMS values were superior in the rings in comparison with the parallel bars and the floor (100, 82, and 73% of the sample, respectively). As observed previously in other muscles, it is worth noting the higher variability of the EMG signal in the rings, in comparison with the EMG outcomes in the other 2 apparatus. The NRMS outcomes of the rectus femoris (Figure 4E), similarly to lateral deltoid and wrist extensors, demonstrated a successive NRMS increments from the floor, to the parallel bars, and to the rings (68% of the sample). Nevertheless, a group effect was only observed in the rectus femoris, which was activated to a lesser extent in AG in comparison with YG (Table 2).

Discussion

The main purpose of this study was to assess the muscle activation when doing the handstand in 3 different conditions. The pattern of muscle activity recorded during a handstand on the floor did not differ significantly in comparison with parallel bars. The only changes were seen in the EMG signal of the forearm muscles, the lateral deltoid, and the rectus femoris muscles. These differences could be explained by the different positions of wrist joints. On the floor, the torque is produced mostly around the transverse axis in flexion and extension motions; on the parallel bars, the torque is generated around the sagittal axis in abduction and adduction motions. On the floor, the wrist flexors are the most active muscle group, which act to determine balance in an inverted position, and the extensors play a supporting role (2,19,35). Parallel bars enforce a specific handgrip, which shows more balanced EMG signal of wrist flexors and extensors. Therefore, the EMG signal of wrist flexors on parallel bars is lower than on the floor, and the activity of extensors is increased. Wrist muscles had the highest %NRMS in each condition, which is supported by studies that have shown that the wrist strategy is the main strategy in maintaining a handstand position (21,40). To complement that main strategy, the shoulder and hip strategies must also be considered. These other 2 strategies are characterized by an increased solicitation of the lateral deltoid and rectus femoris. This greater solicitation could be explained by a lower mobility of the wrist joint because of a lower range of abduction/adduction motions, combined with the lower torque production capabilities of such motions (11).

The muscle activity on still rings differed from that observed on parallel bars and on the floor. Most of the muscles of the gymnasts recorded from showed an increased activity in this condition. Only the triceps brachii did not show any differences on still rings, whereas wrist flexors showed a decrease in their activity. The triceps brachii muscle had a similar level of activation on each apparatus, possibly explained by its fixating role in the elbow joint. During a handstand, the control of balance is performed mainly by the wrist and the shoulder strategy, requiring a higher stabilization of the elbow. The triceps brachii, as the main elbow joint extensor, provides the necessary fixation, and the biceps brachii plays a role in counteracting sudden tilts of the whole body (21,40). In the case of still rings, where wrist joints need to be locked, because of an inability to use the wrist strategy, the shoulder joint plays the main role in controlling balance, which forces the triceps brachii to stabilize the elbow joint (39). In comparison with the floor, the lower activation of the wrist flexors observed on the parallel bars supports the hypothesis that a change in position of the wrist joints as a result of a specific handgrip requires a locking out movement, and therefore less muscle activity.

In general, the muscles operating over the shoulder joint increased their activity during the handstand on still rings. It has been shown that in contrast to a handstand on the floor, gymnasts produce a greater shoulder torque to control the balance. This torque is not generated by transferring the center of mass over the base of support but by moving their hands back under the center of mass (34). Such an increase is necessary to overcome the unstable conditions caused by the sway of the gymnast's body. As a suspended pendulum, still rings are characterized by a lack of opposing frictional forces for movements of the hands and the whole upper limbs in general (39). Therefore, more strength is needed to maintain a static position and thus, higher muscle activation is noted in comparison with that observed on the floor and parallel bars (31). In addition to the unstable characteristics of still rings, the base of support is even more reduced in comparison with the floor condition, where a gymnast can use wide spread fingers. The highest increase of the EMG signal was noticed for the pectoralis major muscle, barely active on the floor and parallel bars, while on still rings it reached approximately 80% of NRMS. The muscle with the second highest activation increase was the trapezius descendens. This may also be explained by use of the shoulder strategy for balance control on still rings. Yeadon, et al (39) also investigated muscle activity during a handstand on the floor and on still rings. They also observed an increase in the EMG signal on still rings in the investigated muscles, and their conclusions were similar to those of this study. When performing a handstand on still rings, it is assumed that balanced muscle activation is required between the wrist flexors and extensors to stabilize the wrist joint, as well as between the biceps and triceps, to stabilize the elbow joint (39). With respect to this rationale, Yeadon, et al (39) observed that locking the wrist joints on the still rings requires a great amount of flexor activity and even greater activity of extensors. However, in this study, only the wrist extensor showed increased activation. It should be considered that, because of different goals, although Yeadon, et al (39) detected differences in the peak values of the rectified EMG signal by selecting time-windows of 20 seconds, in our study we measured mean RMS values averaged from three 5 seconds repetitions. Yeadon, et al (39) focused on obtaining as many natural mechanisms for balance recovery as they could, and this study aimed for best performance. Their study was performed on a single gymnast whose muscle activity may not be representative, as it can be seen in the current study, which showed wide *SDs* between the muscle activation characteristics of participants within groups.

In the study, it was also hypothesized that patterns of muscle activity should change throughout the gymnastic lifespan. Overall, AG muscles exhibit lower activation in comparison with YG, although the differences were significant only for the anterior deltoid, the triceps brachii, the rectus femoris, and the multifidus. This may be due to the high variability of the EMG signal on still rings, as the differences related to age are considered as mean values recorded on 3 apparatus. A lower level of muscle activity in response to the exercise with the same load (body mass) may suggest neuromuscular specialization as a result of long-term training (12,14). Despite lower values of %NRMS, we did not notice any differences in the pattern of EMG signal in different muscles between YG and AG. This outcome could be explained by the fact that although YG and AG differ in their pattern of muscle strength (26), it was shown that there is no association between strength and postural control both in adolescents (18) and adults (29). However, the aforementioned studies concern untrained subjects and lower limbs in an upright stance; therefore, more research on the relationship between upper-limb muscle strength and postural control during handstands should be performed to clarify whether such justification also applies for a handstand.

The main limitations of this study concern the EMG recordings themselves. Because of the stochastic nature of the signal, special care must be taken to reduce its variability. In the study, an arbitrary angle MVC method was used, as the different apparatuses require different hand positions. Thus, some muscles showed elicitations above 100% of their MVC on the still rings. As long as all participants used the same reference contractions and the purpose of the study was to determine the relative changes, their maximal potential should not be an issue (5). Besides constant muscle activity related to the handstand's inverted position, maintaining body balance relies on the ability to rapidly develop muscular force to counteract body perturbations in response to the external force of gravity. Therefore, the observed muscle activity is a blend of the 2. It could be argued that such short lasting contractions should be normalized by means of MVC, however, it has been proven that they can be normalized by the MVC with excellent reliability (intraclass correlation = 0.80–0.90) (4). Another concern is attributed to the fact that the parallel bars and still rings demand handgrip which, by itself, elicits forearm muscle activation, which could cover up the role of the wrist muscles in postural control. However, it has been shown that torque production in the direction of both ulnar and radial deviation (specific for handstand these apparatuses) generates EMG amplitude that easily exceeds 2 times the amount elicited during maximal handgrip (30).

Our results confirm that the unstable conditions of still rings increase the EMG activity recorded from all gymnasts. A different handgrip position between a handstand on the floor and on parallel bars can change the activity of not only forearm muscles but also of distal muscles such as the rectus femoris and deltoids. Finally, the overall lower muscle activity of AG in comparison with YG did not exhibit any difference in the pattern of EMG signal when performing a handstand on the 3 different apparatus.

Practical Applications

The description of muscle activity during a handstand on various apparatus can be helpful in understanding the mechanism of altering wrist strategy in handstand balance control. Such knowledge, despite the fact that it was derived from gymnasts, could also be used to improve handstand performance of acrobats, physical education teachers, and many others who perform this skill. Therefore, coaches who find that their mentees have difficulty performing a handstand on the parallel bars may focus their training on gymnastic elements and muscle conditioning exercises that demand use of the anterior part of the deltoid muscle and the rectus femoris. This suggestion arises from the fact that these 2 muscles show increased activity during handgrip on the parallel bars. It would appear that both muscles are highly solicited to control body balance by the shoulder and hip joints when maintaining a handstand. A more difficult task, such as a handstand on still rings, requires even greater activity of muscles controlling the shoulder joint, especially the pectoralis major, the latissimus dorsi, the biceps brachii, the trapezius descendens, and the deltoid muscles. Thus, training focused on the development of strength and motor control in these muscles should improve handstand performance, in both YG and AG.

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