ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2023; 30(**1**): 13-19
ISSN 2299-9590
DOI: 10.23829/TSS.2023.30.1-2

Prevalence of gymnastics-based movement ability/inability among high-intensity functional training practitioners

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Abstract

Introduction. Gymnastics-based exercises comprise complex movements used in many high-intensity functional training (HIFT) workouts, but the prevalence of ability/inability to perform these exercises is unknown. Aim of Study. This study investigated the rate of practitioners able/unable to perform each gymnastics-based movement applied in HIFT workouts. Material and Methods. Using a "virtual snowball" sampling method 1325 volunteers (women: 738; men: 587) answered an online survey. The rates for the ability/inability were estimated for the following movements: pull-up (PU) and its variations (strict pull-up [SPU], kipping/butterfly PU, strict chest-to-bar [SCtB], kipping/butterfly CtB), strict (STtB) and kipping toes-to-bar (TtB), bar muscle--up (BMU), ring muscle-up (RMU), handstand hold, handstand push-up (HSPU) and handstand walk (HSW). The rates were also stratified according to sex. Results. Our results demonstrated a high rate of inability in strict movements: SPU, SCtB, STtB, strict HSPU, strict BMU, strict RMU, and handstand hold, especially among women. The use of the kipping technique allowed one to perform many of these movements, since the prevalence of inability was lower for kipping movements than for strict ones. The exception was the kipping PU, since among men the percentage of volunteers unable to perform kipping/butterfly PU was slightly greater than SPU, suggesting a deficiency in the technical aspects of this movement. Additionally, kipping BMU, RMU, and HSW were the "dynamic" movements (i.e. excluding the strict ones) with greater rates of inability (≥50%), suggesting the need for more attention by coaches. Conclusions. Our results allow reflecting upon coaches' approaches to teaching complex gymnastics-based exercises to persons without a gymnastic background, as well as reflecting upon further research to develop an understanding of interventions used to improve gymnastics-based exercises, transferring the key research findings into practice.

KEYWORDS: muscle strength, gymnastics, mixed modality training, calisthenics.

Received: 14 September 2022
Accepted: 9 January 2023

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Introduction

High-intensity functional training (HIFT) is defined as an exercise modality involving functional, multi-joint movements, adaptable to any fitness level [4], and comprises the basis of world-renowned programs such as CrossFit™, among others [3, 12]. Its growing popularity is undeniable, with scientific interest in this exercise modality simultaneously increasing [4, 5, 21]. Endurance-based exercises such as running, cycling, and rowing are merged with powerlifting, weightlifting, and gymnastics, performed in a continuous circuit or interval format and conducted at a high intensity [4]. This characteristic design justifies the recent use of the term "mixed modality training" (MMT) [5, 15] to designate this training methodology and, among the cited modalities, gymnastics exercises stand out as the most complex ones.

Indeed, artistic gymnastics comprises complex movements and requires adaptations to take part in HIFT workouts. For example, the ring muscle-up (RMU), one of the most complex gymnastics-based movements in the HIFT workouts, is an adaptation of the movement called "front uprise" in artistic gymnastics (for more details see [23]). RMU execution requires high-level motor skills, such as strength, temporal and spatial orientation, and coordination, which is difficult, but not impossible, to achieve when someone has no previous experience in artistic gymnastics, as the majority of HIFT practitioners around the world.

Other gymnastics-based exercises included in HIFT workouts are pull-up (PU) and its variations (strict pull-up [SPU], kipping/butterfly PU, strict chest-to--bar [SCtB], kipping/butterfly CtB), strict (STtB) and kipping toes-to-bar (TtB), bar muscle-up (BMU), which are exercises performed when suspended from a bar, while RMU is performed when suspended from a pair of rings. The list of gymnastics-based exercises also includes handstand exercises, such as handstand hold, handstand push-up (HSPU), and handstand walk (HSW).

Despite the growing adherence to HIFT programs, owing to the greater sense of community [2, 24], and the fact that gymnastics-based exercises represent a relevant part of HIFT workouts, there are no previous studies investigating estimates of the prevalence of gymnastics-based movement ability/inability among HIFT practitioners.

The present study aimed to estimate the prevalence of the ability/inability to perform these gymnastics-based movements among HIFT practitioners.

Material and Methods

Study design and sampling

This is a descriptive study using a "virtual snowball" sampling method [13]. Conducted from October to December 2021 with HIFT practitioners, through an online questionnaire (appendix) sent by the internet (Instagram® and WhatsApp® platforms) and detailed instructions to volunteers were available on a website. The sampling is a non-probability virtual snowball type, where the volunteers recruit prospective volunteers through their social networks or social communities, which expands the sample like a snowball [13]. The questionnaire was developed using Google Sheets® and presented in Portuguese, thus the sample volunteers were Brazilians or Portuguese speakers around the world.

The purpose and procedures of the survey were explained on the first page of the online form and consent was obtained prior to completing the form. All procedures were approved by the local ethics committee (protocol #3.425.388) according to the Declaration of Helsinki.

Definitions of variables

The online form was developed by the authors and contains 34 questions divided into 5 sections: sociodemographic questions (n = 4), history of physical training (n = 8), personal records of gymnastics-based exercises applied in HIFT workouts (n = 14), perceived and/or measured gymnastic skills (n = 3), perceived and/or measured core endurance (n = 5), with an estimated time of 3 to 5 minutes to answer all questions

The personal records of gymnastics-based exercises applied in HIFT workouts comprised the following movement: PU and its variations (SPU, kipping/butterfly PU, SCtB, kipping/butterfly CtB), STtB and kipping TtB, BMU, which are exercises performed when suspended from a bar, while RMU is performed when suspended from a pair of rings. The list of gymnastics-based exercises also includes the handstand exercises, such as handstand hold, HSPU, and HSW.

Aiming to determine the prevalence of gymnastics-based movement ability/inability among HIFT practitioners, the data from personal records of gymnastics-based exercises applied in HIFT workouts were dichotomized as "Yes", when the volunteer reported being able to complete the specific movement (e.g. BMU), and "No", when the volunteer reported being unable to do it. For handstand hold the parameter was established as "Yes", when the volunteer reported being able to sustain this position for more than 5 seconds with the body aligned (freestanding, without wall support), and for HSW the parameter was established as "Yes", when the volunteer reported being able to walk for at least 1 meter unbroken.

Considering that men tend to be naturally stronger than women [17] and many gymnastics-based movements depend on strength, all descriptive data were analyzed for the total sample and stratified by sex.

Statistical analysis

The dichotomized data concerning the ability/inability of gymnastics-based movements were analyzed descriptively using absolute and relative (i.e. percentage) frequency. Continuous data (e.g. age) from sociodemographic recordings were presented as mean ± standard deviation.

Results

A total of 1325 volunteers (men: 587; women: 738) answered the survey; the mean age of volunteers was 30.8 ± 7.1 (min: 12, max: 71) years old (men: 30.7 ± ± 7.0, min: 14, max: 67; women: 31.0 ± 7.2, min: 12, max: 71 years old). A quarter of volunteers (24.5%; men: 22.8%, women: 25.8%) reported having less than one year of HIFT experience, 39.9% (men: 38.5%, women: 41.0%) reported having one to three years of practice, and 35.6% (men: 38.7%, women: 33.2%) more than three years of practice.

We found 76.4% of volunteers (n = 1325) able to complete at least one SPU, while 52.8% were able to complete SCtB. Considering the kipping and butterfly variations, the prevalence of volunteers able to perform them was 80.7% for PU, and 64.9% for CtB (Table 1). When the sample was stratified according to sex, we found different profiles between women and men. The prevalence of women able to perform strict exercises was lower than men. We found that 61.7% and only 29.9% of women were able to perform SPU and SCtB, respectively, while among men the prevalence was 95.1% and 81.7%, respectively. Considering the same movements, but using kipping/butterfly technique, the prevalence among women was 71.4% and 49.4% for PU and CtB, whereas among men it was 92.5% and 84.5% for PU and CtB, respectively (Table 1).

Table 1. Prevalence of volunteers (n = 1325) stratified by sex (women = 738; men = 587) able to do strict and kipping/butterfly pull-up and chest-to-bar pull-up

	Strict pull-up		
	All	Women	Men
No	23.6%	38.3%	4.9%
Yes	76.4%	61.7%	95.1%
	Kipping/butterfly pull-up		
	All	Women	Men
No	19.3%	28.6%	7.5%
Yes	80.7%	71.4%	92.5%
	Strict chest-to-bar		
	All	Women	Men
No	47.2%	70.1%	18.2%
Yes	52.8%	29.9%	81.7%
	Kipping/butterfly chest-to-bar		
	All	Women	Men
No	35.1%	50.6%	15.5%
Yes	64.9%	49.4%	84.5%

The prevalence of volunteers able to complete at least one STtB was 62.1%, while only 10.2% and 14.1% were able to complete at least one strict BMU and strict RMU, respectively. Using kipping, 81.2%, 42.1%, and 27.5% of volunteers reported being able to complete at least one TtB, BMU, and RMU, respectively (Table 2). For STtB, strict BMU and RMU the prevalence of women able to do each movement was 44.8%, 3.8%, and 6.1%, respectively, while for men it was 83.9%, 18.3%, and 24.2%, respectively. Considering the same movements, but using the kipping technique, the prevalence among women was 71.0%, 20.4% and 10.2% for TtB and BMU and RMU, and among men it was 94.0%, 69.4%, and 49.3% for TtB and BMU and RMU, respectively (Table 2).

Table 2. Prevalence of volunteers (n = 1325) stratified by sex (women = 738; men = 587) able to do strict and kipping toes-to-bar, bar muscle-up (BMU) and ring muscle-up (RMU)

	Strict toes-to-bar		
	All	Women	Men
No	37.9%	55.2%	16.1%
Yes	62.1%	44.8%	83.9%
	Kipping toes-to-bar		
	All	Women	Men
No	18.8%	29.0%	6.0%
Yes	81.2%	71.0%	94.0%
	Strict BMU		
	All	Women	Men
No	89.8%	96.8%	81.7%
Yes	10.2%	3.8%	18.3%
	Kipping BMU		
	All	Women	Men
No	57.9%	79.6%	30.6%
Yes	42.1%	20.4%	69.4%

	Strict RMU		
	All	Women	Men
No	85.9%	93.9%	75.8%
Yes	14.1%	6.1%	24.2%
	Kipping RMU		
	All	Women	Men
No	72.5%	89.8%	50.7%
Yes	27.5%	10.2%	49.3%

Table 3 presents the results from handstand exercises, indicating that 60.5% of volunteers were able to complete at least one strict HSPU and 72.1% were able to complete kipping HSPU. The prevalence of volunteers able to maintain more than 5 seconds of handstand hold was 51.1%, while only 31.2% were able to walk at least 1 meter in the handstand position.

Regarding the handstand exercises, 45.3% of women and 79.7% of men volunteers were able to perform strict HSPU, while 61.3% of female and 85.7% of male volunteers were able to perform kipping HSPU. For the handstand hold, 42.1% of women and 62.5% of men volunteers were able to maintain more than 5 seconds of the handstand hold, while for HSW only 15.0% of women and 51.8% of men volunteers were able to walk at least 1 meter (Table 3).

Table 3. Prevalence of volunteers (n = 1325) stratified by sex (women = 738; men = 587) able to do strict and kipping handstand pushup (HSPU), handstand hold, and handstand walk (HSW)

	Strict HSPU		
	All	Women	Men
No	39.5%	54.7%	20.3%
Yes	60.5%	45.3%/	79.7%
	Kipping HSPU		
	All	Women	Men
No	27.9%	38.7%	14.3%
Yes	72.1%	61.3%	85.7%
	Handstand hold		
	All	Women	Men
No	48.9%	57.9%	37.5%
Yes	51.1%	42.1%	62.5%
	HSW		
	All	Women	Men
No	68.8%	85.0%	48.2%
Yes	31.2%	15.0%	51.8%

Discussion

The present study aimed to estimate the prevalence of gymnastics-based movement ability/inability among HIFT practitioners, and our results allowed us to identify a relatively high prevalence of practitioners unable to perform strict movements, especially BMU and RMU, an inability that was more prominent among female practitioners. The prevalence of practitioners unable to perform HSW was also high, especially among women. Performance in artistic gymnastics routines is linked to strength (static strength, muscle power in the lower and upper limbs), flexibility, and muscular anaerobic endurance [1, 30]. Indeed, static strength is the basis of gymnastics training [25], since it is essential in artistic gymnastics routines, as well as gymnastics-based exercises applied in HIFT workouts [27]. Sommer [25] stated that basic strength, which involves the ability to develop maximal strength at fundamental static positions with bodyweight resistance, is the initial building block, from which all other gymnastics training progresses. In the context of HIFT, these fundamental static positions should be interpreted as SPU, SCtB, STtB, strict BMU, strict RMU and HSPU.

In our study the prevalence of inability to perform at least one repetition of strict movements was high, which represents a barrier to the progress of gymnastics skills, impacting the HIFT workouts progress when gymnastics--based movements are included. Strict BMU and RMU exhibited the highest prevalence of inability with 89.8% and 85.9% of volunteers unable to perform these movements, respectively. Among the strict movements, BMU and RMU were the ones with lower percentage differences between men and women, indicating they were the main deficit, at least in the context of maximal strength, among HIFT practitioners independent of sex. In this context, two aspects should be highlighted: 1) in artistic gymnastics the rings are used exclusively by men, while in HIFT workouts there are no general rules limiting women to perform RMU; 2) despite the high inability to perform strict BMU (89.8%) and RMU (85.9%), the prevalence of inability to perform the cited movements using kipping was relatively lower, 57.9% and 72.5%, corresponding to a difference of 35.5% and 15.5% of volunteers that were unable to perform the

strict BMU and RMU, respectively, but were able to perform these movements using kipping as a technique. Thus, it is possible that the "maximal strength at fundamental static positions" could account for a small part of the factors that influence/determine the ability to perform kipping BMU and RMU, then using the kipping effectively could help to achieve the movement, despite the inability to perform the strict BMU and RMU.

In time, it is also worthwhile to highlight that the relevance of maximal strength should not be excluded as a determinant of kipping BMU and RMU success, since men, who are generally stronger than women, exhibited a greater discrepancy in the percentage of volunteers reporting that they were unable to perform strict BMU and RMU, but able to perform kipping BMU and RMU.

Another interesting aspect to be discussed in the context of technique was the very similar percentage of inability to perform strict BMU and RMU (BMU = 89.8%; RMU = 85.9%; difference = 3.6% greater for BMU), but a considerable discrepancy in the percentage of inability to perform kipping BMU and RMU (BMU = 57.9%; RMU = 72.5%; difference = 14.6% greater for RMU), suggesting the RMU demands greater technique skills. The characteristics of used implements (i.e. bar vs rings) in each movement (BMU vs RMU) could explain this discrepancy, since the bar is a fixed implement, while rings are a mobile implement, demanding greater abilities to control it. Indeed, Santos Rocha et al. [23] discussed the complexity of RMU as a gymnastics--based exercise, and our results corroborate this fact.

The STtB is similar to the hanging leg lifts (HLL) in artistic gymnastics that demand great core strength, requiring specific core strengthening routines, commonly applied by artistic gymnastics, to perform this movement. In our study, 37.9% of volunteers reported being unable to perform at least one STtB. As the HLL is a mandatory component in gymnastic athletes' training programs [25], our result from STtB suggests that HIFT practitioners are not prioritizing the specific core strength training as the artistic gymnastics. Despite the peculiarities of each modality (i.e. artistic gymnastics vs HIFT), core strength seems to be a common skill required for high performance in both modalities [6, 9, 25].

The kipping TtB is a gymnastics-based movement with close technical aspects to kipping BMU and RMU, especially the former one. Like kipping BMU and RMU, the kipping TtB consists of two main phases, the "arch", and "hollow" position. During the kipping BMU and RMU the hollow position is changed with an abrupt hip extension, projecting the hip vertically (see Santos Rocha et al. [23]), whereas during the kipping TtB the hollow position is sustained, progressing with a greater hip flexion aiming to touch the bar with toes. The discrepancy between the percentage of volunteers unable to perform STtB (37.9%) and kipping (18.8%) TtB also indicates that an adequate technique use of kipping could help to achieve the moment, despite the core strength limitations indicated by the inability to perform STtB.

When stratified by sex, our results reveal a greater limitation among women than men to perform STtB (women: 55.2% vs men 16.1% unable to perform the movement) and kipping (women: 29.0% vs men 6.0%) TtB. These data emphasize the need to develop specific strategies to improve core strength, more specifically the engagement and synergy of core and lat muscles, and technical skills for women, aiming to achieve the TtB movement.

The pull-up and its variation, the CtB pull-up are commonly used gymnastics-based exercises in HIFT workouts [16, 29]. In the pull-up the aim is to pull the body from the hanging position (i.e. the body completely extended), aiming for the chin to reach the bar height with the elbows flexed at ~90º [19, 26], while in the CtB the aim is to pull to touch the bar with the chest, requiring a greater vertical displacement, thus also a greater effort. The SPU and SCtB are multi-joint upper-body exercises that are considered valid measures of weight relative to muscular strength [19, 22, 26], in the same sense they are used to improve the upper limb strength when included in gymnastics training routines [25]. Our results show that 23.6% of volunteers reported being unable to perform at least one SPU, and 47.2% were unable to perform a SCtB, a high prevalence of inability to perform two basic exercises in the gymnastic context. As expected the inability was greater among women (SPU: 38.3%; SCtB: 70.1%) than men (SPU: 4.9%; SCtB: 18.2%), since 70.1% of women reported being unable to perform SCtB. Interestingly, the discrepancy between the inability to perform SPU and kipping/butterfly pull-up was very similar, which was also observed for SCtB and kipping/butterfly CtB.

Indeed, kipping/butterfly pull-ups (PU) require a complex technique [7, 20, 29] and our results corroborate this fact. Among men, who are typically stronger than women, the pull-up was the unique movement with the percentage of volunteers unable to perform the strict movement being lower than with the execution with technique (i.e. kipping/butterfly) (SPU: 4.9% vs kipping/butterfly PU: 7.5%; difference = 2.6% greater

for kipping/butterfly PU). It means that kipping/butterfly pull-ups are less dependent on strength and more dependent on technique skills.

The upside-down position, such as the handstand, is not easy to achieve and sustain, because it requires 1) courage, since many persons fear falling being submitted to this position [18], 2) strength to sustain the body weight over the upper limbs [10], 3) good spatial orientation since vestibular, visual and plantar somatosensorial inputs are not reliable/congruent [14]. These requirements could help to explain why 48.9% (57.9% among women and 37.5% among men) of volunteers were unable to sustain more than 5 seconds of a handstand hold. Curiously, the static handstand hold is an essential technique needed to progress to more complex tasks in the context of artistic gymnastics [8].

Regarding strict HSPU, an upper-body, multi-joint exercise designed to increase upper extremity, shoulder, and core stability [11], we found that 39.5% of volunteers reported being unable to perform at least one repetition, indicating a deficiency in strength for an essential pushing task. As expected, the limitation was greater among women than men (54.7% vs 20.3% unable to perform strict HSPU). The use of a kipping technique allowed more volunteers to perform the HSPU, since 27.9% reported being unable to perform at least one repetition of kipping HSPU. Interestingly, the technique seems to favor women to perform the HSPU, since the percentage difference of inability between strict HSPU and kipping HSPU was greater (54.7% minus 38.7% = = 16%) among women than among men (20.3% minus 14.3% = 6%).

The HSW requires the same skills as the handstand hold, adding the fact that the HSW is a dynamic task, which imposes an additive challenge [28]. Thus, this explains the greater percentage of inability to walk at least 1 meter in an upside-down position (i.e. HSW) (68.8%) when compared to the percentage of inability to sustain more than 5 seconds in handstand hold (48.9%). In addition, the rate of inability to perform HSW was greater among women (85.0%) than men (48.2%), drawing attention to the need for an adequate amount of time applied to learn/train this movement, as well as adequate classes to allow adequate technique skill acquisition.

Strengths and limitations

This study provides a detailed descriptive insight into the rate of gymnastics-based movement ability/inability among HIFT practitioners. However, the limitations of the present study should be recognized. This study only included HIFT practitioners from Brazil or Portuguese speakers around the world, and the rates could diverge from countries with a historical culture of artistic gymnastics for children, where the early experience with gymnastics is probably greater. Additionally, this is a cross-sectional study, and the data were recorded through an online survey, thus the precision of reports could not be always guaranteed. Despite this, it should be noted that the sample size of this study was relatively large.

Conclusions

We presented a complete overview of the prevalence of ability/inability to perform gymnastics-based movements among HIFT practitioners. As strict movements are essential for artistic gymnastics, the high rate of inability in these essential movements, for instance, SPU, SCtB, STtB, strict HSPU, strict BMU, and strict RMU, draws attention to the need for additional (i.e. separate) strength training, valuing static strength training of gymnastics-based movements. Additionally, kipping BMU, RMU, and HSW were the "dynamic" movements (i.e. excluding the strict ones) with greater rates of inability (all with more than 50% of inability reported), suggesting the need for more attention within HIFT workouts.

Acknowledgements

The authors thank all volunteers who answered the online survey and help to share as proposed by the "snowball" method. The authors also thank all IRC staff, Dr. Rodrigo Jasbick, and Axel Gouveia for their value considerations throughout the project development.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Atikovic A, Kalinski SD, Čuk I. Age trends in artistic gymnastic across world championships and the olympic games from 2003 to 2016. Sci Gymnast J. 2017;9:251-263.
2. Bycura D, Feito Y, Prather C. Motivational factors in CrossFit® training participation. Health Behav Policy Rev. 2017;4:539-550.
3. Falk Neto J, Kennedy M. The multimodal nature of high--intensity functional training: potential applications to improve sport performance. Sports. 2019;7:33.
4. Feito Y, Heinrich K, Butcher S, Poston W. High-intensity functional training (HIFT): definition and research implications for improved fitness. Sports. 2018;6:76.
5. Figueiredo R, Pereira R, Neto OP. Nonlinear analysis is the most suitable method to detect changes in heart autonomic control after exercise of different durations. Comput Biol Med. 2018;97:83-88.

6. Glassman G. The CrossFit level 1 training guide. CrossFit. 2020.
7. Glassman G. The kipping pull-up. Crossfit Journal. 2005;32:1-3.
8. Grabowiecki M, Rum L, Laudani L, Vannozzi G. Biomechanical characteristics of handstand walking initiation. Gait Posture. 2021;86:311-318.
9. Haddock CK, Poston WSC, Heinrich KM, Jahnke SA, Jitnarin N. The benefits of high-intensity functional training fitness programs for military personnel. Mil Med. 2016;181:e1508-e1514.
10. Hedbávný P, Bago G, Kalichová M. Influence of strength abilities on quality of the handstand. Int J Sport Health Sci. 2013;7(10):602-608.
11. Johnson A, Meador M, Bodamer M, Langford E, Snarr RL. Exercise technique: handstand push-up. Strength Cond J. 2019;41:119-123.
12. Júnior JLNS, Passos R da S, Oliveira AA, da Silva JRD, Souza RS, Passos R de S, et al. The influence of hand guards on explosive force and pain and exertion perception in a hang holding task. Sci Gymnast J. 2021;13:107-117.
13. Kirchherr J, Charles K. Enhancing the sample diversity of snowball samples: recommendations from a research project on anti-dam movements in Southeast Asia. PLoS One. 2018;13:e0201710.
14. 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. Balt J Health Phys Act. 2015;7(4):11.
15. Marchini A, Pereira R, Pedroso W, Christou E, Neto OP. Age-associated differences in motor output variability and coordination during the simultaneous dorsiflexion of both feet. Somatosens Mot Res. 2017;34:96-101.
16. Martínez-Gómez R, Valenzuela PL, Alejo LB, Gil-Cabrera J, Montalvo-Pérez A, Talavera E, et al. Physiological predictors of competition performance in crossfit athletes. Int J Environ Res Public Health. 2020;17:1-12.
17. Nuzzo JL. Narrative review of sex differences in muscle strength, endurance, activation, size, fiber type, and strength training participation rates, preferences, motivations, injuries, and neuromuscular adaptations. J Strength Cond Res. 2022:37(2):494-536. https://doi.org/10.1519/JSC.0000000000004329
18. Omorczyk J, Zajac A, Puszczalowska-Lizis E. Relationships between postural stability in standing and handstand and psychological factors in athletes practicing artistic gymnastics. Balt J Health Phys Act. 2019;11(4):11.
19. Pate RR, Burgess ML, Woods JA, Ross JG, Baumgartner T. Validity of field tests of upper body muscular strength. Res Q Exerc Sport. 1993;64:17-24.
20. Prinold JAI, Bull AMJ. Scapula kinematics of pull-up techniques: avoiding impingement risk with training changes. J Sci Med Sport. 2016;19:629-635.
21. Pritchard HJ, Keogh JW, Winwood PW. Tapering practices of elite CrossFit athletes. Int J Sports Sci Coach. 2020;15:753-761.
22. Ronai P, Scibek E. Exercise technique the pull-up. Strength Cond J. 2014;36:88-90.
23. Santos Rocha JA, Pereira G, Kilipper R, Pereira J, Barsanulfo S, Castro FB, et al. Influence of key-points of ring muscle-up execution on movement performance: a descriptive analysis. Cent Eur J Sport Sci Med. 2020;29:41-51.
24. Simpson D, Prewitt-White TR, Feito Y, Giusti J, Shuda R. Challenge, commitment, community, and empowerment: factors that promote the adoption of crossfit as a training program. Sport J. 2017;1:1-14.
25. Sommer C. Building the gymnastic body: the science of gymnastics strength training. Anthem: Olympic Bodies, LLC; 2008.
26. de Sousa AFM, dos Santos GB, dos Reis T, Valerino AJR, del Rosso S, Boullosa DA. Differences in physical fitness between recreational CrossFit® and resistance trained individuals. J Exerc Physiol. 2016;19.
27. Tibana RA, Neto IV de S, de Sousa NMF, Romeiro C, Hanai A, Brandão H, et al. Local muscle endurance and strength had strong relationship with CrossFit® Open 2020 in amateur athletes. Sports (Basel). 2021;9:98.
28. Uzunov V. The handstand: a four stage training model. Gym Coach. 2008;2:52-59.
29. Williamson T, Price P. A comparison of muscle activity between strict, kipping and butterfly pull-ups. J Sport Exer Sci. 2021;5:149-155.
30. Zasada S, Zasada M, Kochanowicz A, Niespodzinski B, Sawczyn M. The effect of specific strength training on the quality of gymnastic elements execution in young gymnasts. Balt J Health Phys Act. 2016;8:79-91.