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CONTENTS

Science of Gymnastics Journal is now part of social networks.

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EDITORIAL

Dear friends,

The Olympic Games in Paris were a new historic step for many countries. Ireland and the Philippines won the first Olympic gold medal in men's gymnastics, while Italy can be proud of the same achievement in women's gymnastics. In rhythmic gymnastics, China in the group and Germany in the individual event won their first Olympic gold medals. Great Britain also won its first gold in trampolining. Gymnastics is spread across the globe, but we have missed out on some good gymnasts for political reasons and also experienced some unfair moments.

Another step our journal has taken is that we have been accepted into the DOAJ base as they recognize a journal that meets all their requirements.

Since October, our magazine has been presented on social networks such as X, Facebook and Instagram. You are all welcome to participate and spread the published knowledge.

Flavio Bessi from the University of Freiburg (Germany) has once again organized a good symposium on gymnastics. You can find his short report in the 'Letter to the editor' section.

Unfortunately, we still have problems with our reviewers, as many of them do not have the time to review our submissions. I would like to appeal to you to help us in this matter. As a scientific journal, we only have access to a limited number of researchers. Let us try together to remain a part of the prominent scientific community in the Web of Science and SCOPUS!

This issue covers a broad spectrum of content. The authors come from Croatia, Serbia, the Czech Republic, Greece, Spain, Portugal, Iran, Bosnia and Herzegovina, Germany and Brazil.

Anton Gajdoš, together with Ivan Čuk XXXI, has prepared a short historical note in which the world champion Peter Šumi, all-around champion of 1922 and 1926, is introduced.

Just a reminder: If you quote the magazine, its abbreviation in the Web of Knowledge is
SCI GYMN J.

Please note that our address is

https://journals.uni-lj.si/sgj

I hope you enjoy reading and wish you many new ideas for research projects and articles.

Ivan Čuk
Editor-in-Chief

Science of Gymnastics Journal being present at The XVIII. International Freiburg Gymnastics Congress 2024 (photos: Maja Pajek)

From the left: Monèm Jemni, Michel Marina, Alexander Seemann-Sinn, Hardy Fink, Karmen Šibanc, Maja Pajek & Flavio Bessi

From the left: Maja Pajek, Hardy Fink and Karmen Šibanc

EXPERIENCE OF CZECH ELITE TRAMPOLINISTS AND THEIR COACHES WITH LOST MOVE SYNDROME

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Abstract

This exploratory qualitative study explored the experience of Czech elite trampolinists and their coaches with Lost Move Syndrome (LMS). Six in-depth semi-structured interviews were conducted with three trampolinists (aged from 13 to 20 years) and their coaches (aged from 45 to 46 years with coaching experience ranging from 20 to 28 years). Statements were analysed using interpretative phenomenological analysis. The results contributed to the mapping of this essential but not well-described phenomenon in the literature, showing, in particular, the significant variability in the perceived causes of LMS. Physical manifestations of LMS in individual trampolinists were quite different. Fear and misunderstanding of LMS were common psychological issues in all trampolinists. At the same time, there were significant differences between the experience of LMS by trampolinists and their coaches. The most crucial factor for understanding LMS appears to be personal experience with LMS. The results may be helpful for coaches in practice or sports psychologists to understand trampolinist's experience of LMS further.

Keywords: *Lost Move Syndrome, Lost Skill Syndrome, trampoline jumping, interpretative phenomenological analysis*

INTRODUCTION

Lost Move Syndrome (LMS) remains a perplexing phenomenon, not only for trampolinists and their coaches but also for researchers (Heinen, Ghesneh, & Fink, 2016). It is a psychological condition in which an athlete is suddenly unable to perform a movement that was previously automatic (Day, Thatcher, Greenlees, & Woods, 2006). This experience has affected elite athletes, such as double Olympic trampoline medalist Bryony Page and gymnast Simone Biles. LMS can occur in various sports, including javelin throwing (Collins, Morris, & Trower, 1999), as flikkikammo in artistic gymnastics and cheerleading (Maaranen, Van Raalte, & Brewer, 2020), dartitis in darts (Przyborowski, 2023), target panic in archery (Prior & Coates, 2020; Rooke, 2023), and yips in golf (Adler et al., 2003; Clarke, Sheffield, & Akehurst, 2015; Klämpfl, Lobinger, & Raab, 2013). The term Lost Move Syndrome is commonly used in relation to trampoline, gymnastics, and diving (Bennett, Hays, Lindsay, Olusoga, & Maynard, 2015). The literature also references an equivalent term, Lost Skill Syndrome (LSS). Additionally, this condition is sometimes called Temporary Skill Confusion, emphasizing its temporary nature, suggesting it is a solvable problem rather than a permanent loss of skill (Heinen et al., 2016).

There are only a few studies investigating trampolinists' experiences with Lost Move Syndrome (LMS). Previous research has explored the emotional, cognitive, and physical components associated with trampolinists' experiences of LMS (Bennett, 2015). Some investigations have linked LMS to the yips, a psychoneuromuscular dysfunction that occurs during the execution of strokes in golf putting (Smith et al., 2003). This research has focused on the association between personality traits—such as perfectionism, rumination, and reinvestment—and the occurrence of LMS or yips in athletes (Bennett et al., 2016).

There is also no consensus among researchers regarding the classification of LMS. In the study by Silva (1994, as cited in Day et al., 2006), LMS was classified as a sports performance phobia, manifesting as a fear of specific movements. Bennett, Bickley, Vernon, Olusoga, and Maynard (2017) suggested that, due to the emotional experiences and coping mechanisms athletes use to manage LMS, it shares similarities with trauma-related disorders. Bennett and Maynard (2017) further proposed that LMS may be a form of anxiety disorder.

To the best of our knowledge, this is likely the first study on this topic conducted in Czechia. The research aimed to explore the personal experiences of elite trampolinists and their coaches with Lost Move Syndrome (LMS). Specifically, we focused on the components that accompany the onset and progression of LMS, as well as the protective and harmful factors that influence the recovery process. The final objective was to identify the strategies used by trampolinists and their coaches to mitigate the effects of LMS.

METHODS

Given the research aims, questions, and the number of elite athletes with LMS experience, a qualitative research design was chosen. This was carried out through six in-depth, semi-structured interviews, which were analyzed using interpretative phenomenological analysis. Participants were recruited via purposive sampling. The inclusion criteria for trampolinists in the study were based on at least one of Tenn’s (1995, as cited in Day et al., 2006) diagnostic criteria for LMS: a) an inability to take off for at least one somersault when previously able, b) an inability to perform a somersault with a specific degree of twist when previously able, c) switching to a different move midway through when previously able to perform the desired move, or d) an inability to land a particular move when previously able. It was necessary that at least one of these criteria had been met within the last two years and was not the result of a previous injury. The researcher assessed this fulfilment based on observations during training/competitions, reports from the trampolinist’s coach, and self-reports from the trampolinist. Thus, six participants were included in the study, as shown in Table 1:

Table 1:
Information about participants

Trampolinist	Gender	Age	Length of sports training (in years)	Coach	Gender	Age	Length of coaching experience (in years)
Participant 1	M	20	10	Coach 1	F	45	22
Participant 2	F	20	11	Coach 2	M	46	> 20
Participant 3	F	13	9	Coach 3	F	46	28

All trampolinists had experience in international competitions, and pseudonyms were used to protect their identities. The interviews ranged in length from 35 to 95 minutes. The analysis followed the procedure outlined by Smith and Fieldsend (2021). The process began with the researcher's personal reflection on the topic, followed by a pilot interview, which was later included in the data analysis. Each interview was transcribed verbatim, and descriptive notes were added to the text, with in vivo coding applied multiple times. After completing the first interview, the remaining interviews followed the same process.

To ensure validity and trustworthiness, another psychologist and the thesis supervisor had access to the interviews and field notes to maintain objectivity.

RESULTS

Data analysis was conducted separately for the trampolinists and their coaches. In the final stage, differences in the perception of LMS experiences between the trampolinists and their respective coaches were discussed. Several main themes emerged from the analysis: causes, manifestations, factors influencing the course of LMS, consequences, recovery strategies, and sources of information (the latter applicable only to coaches). Table 2 presents the themes that emerged from the interviews.

***Trampolinists*:**

There was considerable variability in the perceived causes of LMS in trampolinists. A common element among all participants was that they were experiencing a subjectively challenging period at the time LMS developed. Participant 1 attributed the causes to the sporting environment, citing overtraining, technical errors in skill execution, and changes in body center of gravity due to physical activity. In contrast, Participant 2 identified causes outside the sporting environment, including a long break from training due to COVID-19 restrictions, low self-esteem, and significant life changes. Participant 3 mentioned a diagnosis of crossed eye and hand laterality by a psychologist, along with mental overload from learning numerous new skills.

The manifestations of LMS were categorized into physical and psychological. The physical symptoms varied across participants. Participant 1 unintentionally performed three and three-quarter front flips instead of a triple front flip, and the LMS spread from one skill to others. Participant 2 experienced muscle stiffening, which prevented her from initiating or executing the affected skill properly, particularly forward somersaults with twisting rotation. She also reported tremors and chest tightness before attempting the affected skills. For Participant 3, the primary physical manifestation was unintentional backflips.

The psychological manifestations were predominantly linked to negative emotions. Participant 1 was the only one to report a positive emotion, describing joy at encountering a new challenge. Common psychological reactions across all trampolinists included fear and confusion: *"Mostly, I did not understand it... I thought it was unfair. I was like, why, why me, why. Like what I am, what I did..."* (Participant 2). The fear stemmed from a loss of control over their bodies, the risk of injury, and concerns that they might never overcome LMS, potentially leading to the end of their athletic careers. For Participant 3, the fear extended to the sport itself, as she felt anxious just at the mention of the training hall. Additional psychological manifestations included fatigue, anxiety, guilt toward the coach, feelings of having a foreign body, issues with backward rotation, and a sense of disconnection between the brain and body: *"...like I had a foreign body, and my brain was not cooperating with my body. I didn't even know why it was happening. My body felt like a stranger to me"* (Participant 3).

Table 2:
Higher-order and lower-order themes from the interviews with trampolinists and coaches

Higher-order Themes	Lower-order Themes Trampolinists	Lower-order Themes Coaches
Perceived causes	Overtraining *(P1)* Technical error in skill *(P1)* Change in centre of gravity *(P1)* Many changes in life *(P2)* Low self-esteem *(P2)* Long pause *(P2)* Mental overload *(P3)* Crossed eye and hand laterality *(P3)*	Change in body constitution *(C1)* Personality characteristics *(C1, C3)* Lack of rest *(C1)* Environmental influences *(C2)* Weight Loss *(C1)* Marijuana *(C1)* Overthinking *(C2)* Over-motivation *(C2)* Overtraining *(C3)* Pressure of difficulty *(C3)*
Manifestations	Physical *(P1, P2, P3)* Psychological *(P1, P2, P3)*	Physical *(C1, C2, C3)* Psychological *(C1, C2, C3)* Psychological in coaches (*C2, C3)*
Factors influencing LMS	Competitions *(P1, P2)* Pressure to perform *(P1)* Fatigue *(P2)* Stress *(P2)*	Stress *(C1)* Pressure *(C1)* Relationships *(C1)* Gender *(C1)* Coacher's own experience *(C2, C3)* Covid-19 *(C2)* Self-confidence *(C2)* Mood *(C3)*
Consequences	Negative *(P1, P2, P3)* Positive *(P1, P2, P3)*	Negative *(C2)* Positive *(C1, C2, C3)*
Recovering strategies	Nonfunctional *(P1, P2, P3)* Functional *(P1, P2, P3)* Partially non/functional *(P2, P3)*	Nonfunctional *(C1, C2, C3)* Functional *(C1, C2, C3)* Partially non/functional *(C1, C3)*
Sources of information		Psychologist *(C1)* Internet *(C1)* Other coaches *(C1, C2, C3)*

Note. P1 = Participant 1, *P2* = Participant 2, *P3* = Participant 3, *C1* = Coach 1, *C2* = Coach 2, *C3* = Coach 3

Participants 1 and 2 identified competitions, performance pressure, fatigue, and stress as factors influencing LMS: *"It is possible that the atmosphere [in a competition] is different, and the routine is different, which completely eliminated the manifestations of LMS for me..."* (Participant 1).

Negative consequences included decreased training confidence and self-esteem, a negative impact on life, impaired competition performance or complete absence from competitions, and the feeling that the trampolinist might never fully regain proficiency in the affected skill. As Participant 2 expressed, *"... but it just symbolizes some sort of intrinsic value for me. Because when I have LMS, I feel like my self-worth is lower."*

Despite these challenges, the LMS experience also highlighted the trampolinists' strengths, such as discipline, and taught them valuable skills, including working with fear and improving communication. Participants 2 and 3 reported increased confidence in their ability to handle future difficulties.

The strategies used to recover from or minimize the manifestations of LMS were categorized into three types: functional, partially functional, and non-functional. These strategies were tailored to address the main symptoms of LMS and were influenced by the coach's personality, the training process, the social environment, and other factors.

Neither Participant 1 nor Participant 2 found that additional training sessions during the training camp were beneficial. Participant 2’s non-functional strategies were largely related to her social environment—such as watching other trampolinists in training who exhibited different manifestations of LMS. A prominent theme in Participant 2's interview was a lack of understanding from her social environment, especially from other coaches. She felt that while the coaches intended to help, their methods often exacerbated her issues: *"... I think all the coaches are trying to help me, but they just don't know how. Moreover, when they try to help, it sometimes makes things worse for me."* (Participant 2). Participant 2 also felt very uncomfortable training with another coach if her own coach was absent.

For Participant 3, taking a month's break from training proved counterproductive, as she felt even more fearful upon returning. She described her experience: *"... so I took like a month off, thinking it might help, and then when I came back, I was scared even to do a simple straight jump. I was like, 'I do even mind just standing in the middle of the trampoline.”* (Participant 3).

For Participant 1 and Participant 2, unlike Participant 3, taking a break was also significant. Participant 1 took about a month off around the time of the interview to recharge for the new season. Participant 2 had a one-week break during LMS to rest from the trampoline environment.

Each trampolinist adopted specific training routines to address LMS. Participant 1 focused on performing more accessible skills and returning to basics. Both Participant 1 and Participant 2 used a foam pit in their training, which allowed them to practice affected skills without difficulty. Participant 2, due to her fear of injury, implemented strategies to ensure safety. She used throwing mats, placed catchers on either side of the trampoline, and relied on hand-catching assistance directly from the coach. Concentration techniques and visualizing a white wall with no thoughts also helped her.

Participant 3 employed various aids on the trampoline, such as colored wheels (about the size of a table setting) and different spotting blocks. She found visualizations particularly helpful for managing fear. Before each workout, she mentally chased away the "monster" that represented her fear.

Participant 2 worked with psychologists during her experience with LMS. She felt that while the psychologists helped her understand LMS, they were unable to eliminate the symptoms. Participant 3 also benefited from working with psychologists, finding their exercises helpful. However, she felt that sorting things out in her own mind was more effective. Social support was another crucial factor for her. The encouragement from her family was particularly positive, especially during breaks from jumping when her family engaged in other sports activities with her. Conversely, she was negatively influenced by other team members and the competition environment.

***Coaches*:**

The development of LMS was perceived by the coaches as the result of a range of significant internal and external influences. They also noted causes related to past experiences with other trampolinists. Coach 1 mentioned factors such as changes in physical constitution, lack of rest, and marijuana use as potential causes for LMS. She also suggested a possible link between weight loss in adolescent girls and resulting energy deficits. Coach 2 identified causes that were primarily external to the sporting environment. These included personal life changes for the trampolinist, such as a change of school or parental divorce, and external pressures from the surrounding environment. Over-motivation by both the trampolinist and the coach, as well as pressure related to the difficulty of routines and specific personality traits, were also mentioned as contributing factors.

Coach 1 reported physical manifestations similar to those described by Participant 1. However, the manifestations reported by Coach 2 and Coach 3 differed from those experienced by the trampolinists. Coach 2 observed behaviors such as reduced jumping and stopping before attempting the affected elements. Coach 3 believed she recognized the early signs of LMS before Participant 3 was aware of them. According to Coach 3, Participant 3 struggled to fully bounce into the skills and began to break down into simpler skills. Over time, Participant 3's condition deteriorated to the point where she could not stand on the trampoline without experiencing negative emotions.

In addition to the physical manifestations, the coaches noted several psychological symptoms observed in the trampolinists. These included loss of interest, negative emotions such as anger, sadness, fear, frustration, and helplessness, as well as feelings of misunderstanding, underestimation, and fatigue.

For Coach 1 and Coach 3, psychological manifestations also emerged as a theme. Coach 1 experienced inner restlessness and a fear of injury during training, which she attempted to conceal. Coach 3 felt peer pressure stemming from the expectation to assist Participant 3 effectively. Additionally, Coach 3 experienced regret and occasional guilt regarding the training practices she had implemented: *"I would even say at one point I felt guilt about it. Yeah, to the point where I was like, 'What do they [the trampolinist's parents] think? Am I to blame? We're struggling because I chose some bad training practices."*

An important factor was the coaches' own experience with LMS. Two coaches shared that this experience led to a deeper understanding of the trampolinists. Coach 2 stated, *"I would say that really, if you haven't experienced it, you can't fully pinpoint or explain the feeling. It's something that someone who hasn't gone through it might not completely understand."* Similarly, Coach 3 remarked, *"Many coaches who haven't experienced it personally struggle to understand how challenging it is. They can't grasp the full extent of the difficulty."*

Both coaches felt that the LMS experience was non-transferable and challenging to explain. They also mentioned factors such as stress, pressure, interpersonal relationships, and the mood with which a trampolinist arrives at training sessions.

Participant 2's exclusion from the Czech national team was the only negative consequence mentioned by the coaches. However, the positive consequences of LMS were notable and can be categorized into those affecting the coach-trampolinist relationship and those affecting only the coach.

For the coach-trampolinist relationship, a strong friendship developed between Participant 1 and his coach. Coach 2 experienced improved open communication, while Coach 3 felt a deepening of mutual trust.

The LMS experience was significant for the coaches individually as well. Coach 3 gained insight into the complexity of working with individuals experiencing LMS, understanding that there is no one-size-fits-all approach.

Most strategies used to recover from LMS were classified as functional or non-functional; some could not be clearly categorized. Coaches described both strategies employed by the trampolinists and those used by the coaches themselves during training sessions.

Coach 1 identified listening to what the trampolinist wanted to jump, rather than following a structured training plan, as a non-functional strategy. Coach 2 noted that it was counterproductive for the trampolinist to attempt the affected skills at every training session, as this could exacerbate frustration from repeated failures. Coach 3 found it dysfunctional to create pressure on Participant 3 and to be overly directive in her training approach. Another dysfunctional strategy involved downplaying the LMS symptoms and neglecting the trampolinist's feelings: *"Just not paying any attention to it, downplaying or simplifying the problem did not work. Saying things like 'It's going to be okay, come on,' without addressing feelings at all, was a poor approach."* (Coach 3)

Coach 1's strategy included communicating with the trampolinist outside of training sessions and ensuring that Participant 1 felt comfortable during training. Coach 3 found group training sessions to be preferable to individual ones, as they provided support from other team members. Other strategies employed were methodical skill progression, approaching the affected skill from a new perspective, explaining instructions differently, and using trampoline aids. Coach 2 observed that Participant 2 motivated herself with small things, such as buying a new leotard. Additionally, Coach 2 recommended that Participant 1 take two breaks from training during the LMS period, both of which were reported to be beneficial. However, the symptoms of LMS did not disappear after either break.

Source of information

All three coaches agreed that discussing LMS with other coaches is a valuable source of information. Coach 2 observed that LMS is frequently discussed at competitions, workshops, and other events. However, it is often concluded that LMS has various causes and manifestations, making it challenging to identify a single recovery method. Coach 3, on the other hand, felt that LMS is an under-discussed topic among coaches, despite its common occurrence. Coach 1 also used the internet and consulted with a psychologist as additional sources of information.

In general, the perceived causes of LMS are similar across the two trampolinist-coach pairs. However, significant discrepancies emerged between the trampolinists' experiences of LMS and the coaches' perceptions of these manifestations. Coaches tended to focus more on obvious physical symptoms (e.g., low jumps), while athletes described their internal feelings (e.g., muscle stiffness, inability to move, chest tightness). Additionally, trampolinists reported more negative consequences of LMS than their coaches did. This discrepancy could suggest that coaches may be underestimating the severity of LMS's impact on athletes.

DISCUSSION

The results of the interpretative phenomenological analysis highlight the varied causes perceived by both trampolinists and their coaches. While the literature generally classifies LMS as a psychological condition (Day et al., 2006), this research reveals that physical factors—such as changes in the body's center of gravity or overall changes in body constitution due to growth or physical activity—are also identified as causes by trampolinists and coaches. Statements from both groups make it challenging to distinguish whether these factors are causes of LMS or manifestations of it. For instance, it is unclear whether excessive fatigue results from overtraining syndrome and thus contributes to LMS, or if it is a manifestation of LMS itself.

The causes, manifestations, and progression of LMS varied widely among participants. Although all three trampolinists met the diagnostic criteria for LMS, the physical manifestations experienced were quite distinct for each individual.

Consistent with Bennett et al.'s (2015) research, fear was identified as the most common psychological manifestation of LMS among trampolinists in our study. The literature does not reach a consensus on whether this fear is specifically related to the risk of injury. In our study, Participant 2 explicitly described a fear of injury, while Participant 1 perceived danger from situations that could potentially lead to injury. This aligns with Day et al.'s (2006) research, which highlighted pressure from upcoming competitions as a significant source of stress.

The results suggest that personal experience with LMS is a crucial factor in understanding the condition. Both trampolinists and coaches who have experienced LMS firsthand believe in the non-transferability of this experience. Coaches with personal LMS experience might interpret their mentee's situation through the lens of their own experience. However, the manifestations of LMS can vary significantly, meaning that even with similar experiences, the perception of LMS may differ between coaches and trampolinists. Nonetheless, having personal experience with LMS contributes to a deeper understanding of trampolinists' challenges with the condition.

The analysis results suggest a potential issue with the involvement of psychologists in trampoline jumping. Cooperation with Participant 2 was significantly impacted by the psychologist’s unfamiliarity with the trampoline environment. This highlights the previously noted need for psychologists to understand the specific context and demands of a sport to effectively collaborate with athletes (Williams, Butt, & Kavanagh, 2023).

There were disagreements among participants regarding communication about LMS. Coach 2 felt that the topic of LMS was sufficiently addressed. In contrast, Coaches 1 and 3 consistently believed that it did not receive enough attention. According to our participants, some coaches deny the existence of LMS. It was also noted in the interviews that excessive communication about LMS might lead to overthinking, potentially exacerbating the condition. This aligns with Bennett et al.'s (2016) findings that trampolinists with higher rumination scores have a higher prevalence of LMS. The suggestion that overthinking might contribute to LMS indicates that some coaches are implicitly aware of the increased likelihood of LMS in athletes who ruminate more. However, this knowledge seems to be based on experience rather than formal understanding.

The mechanism of LMS development is not well described in the literature, nor is it widely understood in the sports environment. This is evident from the lack of emphasis placed on the initial manifestations of LMS by the trampolinists interviewed in this study. Overall, there appears to be a scarcity of scientific literature on LMS, leading coaches to rely on peer experiences and the insights of other coaches to form their understanding of the condition.

A limitation of this study is the small number of participants, which means the findings cannot be considered theoretically saturated. Including additional trampolinists and coaches would likely yield more comprehensive results. Another limitation is the significant age difference among participants, particularly among trampolinists. Different developmental stages (e.g., psychomotor, physical, and psychological development) and the varying influence of parents or peer groups may affect the emergence and development of LMS.

Additionally, the study's focus on subjective experiences may introduce biases, either conscious or unconscious, in participants' responses. Based on the researcher's observations, LMS manifestations also occur during competitions, although at least one participant did not acknowledge this in their interview. The time elapsed between the interview and the LMS experience might also affect the accuracy of the participants' recollections, though it could also allow for a more reflective perspective on the intense emotional experience of LMS. Lastly, the researcher’s limited experience with semi-structured interviews and the chosen method of data analysis are also notable limitations.

CONCLUSION

Our results reveal significant variability in both the manifestations and perceived causes of Lost Move Syndrome (LMS) among trampolinists. The experience of LMS is notably challenging for trampolinists, primarily due to its severe psychological impact. There are distinct differences in how trampolinists and their coaches perceive LMS, with personal experience being a crucial factor in understanding the condition. Misunderstandings or perceived misunderstandings from the social environment emerged as a central theme in the interviews.

These findings provide a foundation for future research on LMS. Exploring mental blocks across various sports could offer valuable insights and potentially improve our approach to LMS and other related psychological challenges. The insights gained from this exploratory study may also assist coaches and sports psychologists in better understanding and addressing the experiences of trampolinists dealing with LMS.

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AN EFFICIENT METHOD TO EVALUATE AND ENHANCE SPORT JUDGES' PERFORMANCE DURING COMPETITION: A CASE STUDY IN ACROBATIC GYMNASTICS

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Abstract

Who judges the gymnastics judges? How do we measure their accuracy and concordance? How do we know if the judging process is fair? The superior jury has this responsibility. However, they normally lack time to provide effective feedback during competitions.

Using macro functions to process statistical and mathematical statements, we designed and validated an automated Excel-based tool called the Automatic Acrobatic Gymnastics Judges Individual Report Tool to evaluate judges' performances quickly and easily during competition, automatically creating and exporting individual reports showing each judge's accuracy and concordance performance on a daily basis, rather than after the competition is ended.

We present empirical data for 76 experienced international judges evaluating acrobatic gymnastics routines in four major official events. A total of 1240 individual reports were analyzed and sent confidentially to the judges during the competition, and 952 were analyzed to evaluate whether this feedback was effective in improving judges' performance during the competition.

The tool provides efficient and easily understood evidence-based feedback on acrobatic gymnastics judges' performance during competition, quickly and automatically creating, analyzing and sending individualized information to judges, thus helping with specific Technical Committee scoring control tasks during competitions. We suggest that judges' performances remain high or are enhanced after receiving daily evaluation during major competition events.

Keywords: *Excel-based tool, Acrobatic Gymnastic, Judges, Evaluation, ACROAJIR®*

INTRODUCTION

Judges are often criticized and sometimes undervalued in sports. In subjectively assessed sports, judges may collude, giving higher scores to their own athletes and lower scores to others. To prevent this, federations implement various strategies, such as automatically eliminating the highest and lowest scores or involving a referee judge (Gambarelli et al., 2012). Gymnastics judges must observe and assess the quality of performances, often processing large amounts of information (Dosseville et al., 2014). Their scores can be influenced by factors such as their viewing position (Dallas et al., 2011; Plessner & Schallies, 2005), serial position bias (Plessner & Schallies, 2005; Fasold et al., 2012; De Bruin, 2005), conformity bias

(Auweele et al., 2004; Boen et al., 2006, 2008, 2013), or the performance of the preceding gymnast (Damisch et al., 2006; Kramer, 2017).

Knowledge, experience, and psychological factors such as attention, emotion recognition, and possible interventions may reduce judges' biases or stress, helping to avoid scoring mistakes (Flessas et al., 2015; Ste-Marie, 2000; Van Bokhorst et al., 2016). These factors can influence the outcome in sports where scoring and ranking depend on subjective evaluations. Gymnastics judges' performance can vary widely, but who judges the judges? Typically, other judges form a superior jury, whose evaluations occur post-competition. Some research has examined judges' overall performance in terms of reliability or concordance after events (Bučar et al., 2012; León-Prados & Jemni, 2022; Leskošek et al., 2018; Mercier & Heiniger, 2018; Premelč et al., 2019); however, none has focused on judges' work during competitions on a day-to-day basis.

Such evaluation requires careful monitoring of judges' accuracy and concordance, which demands significant time and effort at the end of each competition day. In real events, this can be challenging, as judges are often fatigued, and statistical and mathematical expertise is needed for these evaluations.

The FIG, in collaboration with Longines and the Université de Neuchâtel, designed and implemented the Judge Evaluation Program (JEP) for five gymnastics disciplines: Artistic, Acrobatic, Aerobic, Rhythmic Gymnastics, and Trampoline. This program analyzed the marks given by execution judges at international competitions during the 2013–2016 Olympic cycle (Heiniger & Mercier, 2021; Heiniger & Mercier, 2018; Mercier & Heiniger, 2018; Mercier & Klahn, 2017). The authors claimed that the JEP helps to ensure judges' objectivity during gymnastics competitions, allowing for post-competition analysis and an overall evaluation of judges by the respective Technical Committees (TCs). This post-competition control can be applied in competitions where the use of IRCOS (Instant Replay & Control System) is mandatory (FIG, 2020). Judges' scores must demonstrate accuracy, precision, consistency, and the absence of bias. The JEP evaluates gymnastics judges' performance compared to their peers, distinguishing between erratic and precise judges and detecting potential cheating or unintentional misjudging.

Since its inception in 2006, the JEP has evolved iteratively, although earlier versions were criticized for using unsound and inaccurate mathematical tools that didn't always evaluate what was intended. However, a new core statistical engine introduced in the 2013–2016 Olympic cycle provided more reliable feedback to judges and executive committees (Mercier & Heiniger, 2018). The FIG typically derives control scores using external judging panels and post-competition video reviews. This post-competition control establishes expert scores (considered "true scores") against which judges' scores are compared, ensuring evaluation on the fairest possible basis. Expert scores are provided by TC members, who individually assess each exercise (FIG, 2015).

However, previous studies have not clarified whether judges received their individual results after competitions or if they were given specific feedback on their performance during each session within competition days. The FIG has encouraged continental committees and national federations to adopt a similar system for their own events, which inspired our research (FIG, 2020).

How could we obtain this type of information about judges' performance in Acrobatic Gymnastics (ACRO) during real competitions? Could rapid daily feedback improve judges' performance and lead to fairer, more precise judging? Currently, in the absence of more objective feedback, judges rely on the only available in-competition feedback—the final trimmed mean execution and artistic score displayed on the scoreboard. The scores from the in-competition control panel remain unknown to the judges, even after the competition ends.

This study developed and implemented the Automatic Acrobatic Gymnastics Judges Individual Report Tool (ACROAJIR®) (Leon-Prados & Rosales, 2019) as a pedagogical tool to evaluate ACRO judges' performance in real-time, providing objective feedback on their work and potential judging impacts.

METHODS

This study had two goals: a) The ACROAJIR® design; and b) its practical application with judges in real events.

The ACROAJIR® Design

All the official Execution (E) and Artistic (A) scores were collected confidentially and were provided by SmartScoring, the European Gymnastics exclusive results service provider (Bakú, Azerbaijan).

Control scores validity. Looking for the true score

In practice, true performance level is unknown and we must work with approximations. In our study, we assumed that the highest category judges in the Superior Jury who provide the Technical or Artistic Control Scores (E/A C-Score), represented the “truer score” when they judged a competitive routine, compared to lower-level judges.

We proposed a model with two key considerations: 1) the Superior Jury’s scores are considered more representative of the performance, and individual judges’ deviations from the overall judging panel define their performance level; and 2) the model is based on the pre-defined tolerances established by the FIG for judges’ reference (FIG, 2017). If the scores for a routine fall outside this pre-defined deviation among the control judges, they must re-judge the routine using video recordings. This process could yield scores closer to the "true score" and provide better feedback on judges’ performance. Control scores can only be adjusted if the deviation between scores exceeds the allowed tolerance.

The "true score" is determined by the E/A C-Score, averaging three E/A C-scores: two expert judges’ scores from the Superior Jury, plus the Chair Judge’s score from the judging panel. All three expert scores for each E- and A-C score must fall within the allowed deviation. To ensure this, we used the coefficient of variation (CV), where CV = (Standard Deviation / Mean) * 100. The CV takes into account the weighting variable, as judges are generally more accurate when assessing higher-quality performances than lower-quality ones (Mercier & Heiniger, 2018). Since judging variation increases as scores decrease, the allowed inter-judge deviation thresholds increase with the number of deductions.

This means that the same absolute deviation between judges results in a higher dispersion when lower penalties are applied. In our model, when the average total deductions are less than 1 (resulting in a score of 9 or higher), a higher CV doesn’t necessarily indicate high variability, and a more accurate measure of score variability can be obtained from the classification rate, based on total deductions from a maximum of 10 points. We established different acceptable CVs for each 0.5 deduction from 10 points, all within the allowed deviation for each score range (Table 1).

In the ACROAJIR® Excel tool, a "control scores validity macro" was implemented to process all mathematical calculations and quickly detect significant differences between control judges’ scores. When the difference between control judges exceeds a specific threshold, a video review becomes compulsory to redefine the true score accurately.

Table 1.

Examples of cases of control scores allowed (case A) and not allowed (case B), with the least differences between them, to check the acceptability of the control score as the "true score" for each range of scores. The grey boxes provide an example of a non-allowed control judge score, according to the allowed deviations for each range of scores. The same criteria could be applied to artistic scores.

Routine range scores	**10.0 to 9.5**		**9.499 to 9.0**		**8.999 to 8.5**		**8.499 to 8.0**		**7.999 to 7.5**		**7.499 to 6.5**	
Maximum inter-score deviation allowed/range score	0.1		0.2		0.3		0.4		0.5		0.6	
Case examples	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
SJ-E1 score	9.8	9.8	9.3	9.3	8.9	8.9	8.5	8.5	7.9	7.9	7.4	7.4
SJ-E2 score	9.8	9.8	9.3	9.3	8.9	8.9	8.5	8.5	7.9	7.9	7.4	7.4
CJP-E3 score	9.7	9.6	9.1	9.0	8.6	8.5	8.1	8.0	7.4	7.3	6.9	6.8
Average E control score	9.767	9.733	9.233	9.200	8.800	8.767	8.367	8.333	7.733	7.700	7.233	7.200
Maximum inter-score deviation	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.5	0.6
Total SJ-E1penalties	0.2	0.2	0.7	0.7	1.1	1.1	1.5	1.5	2.1	2.1	2.6	2.6
Total SJ-E2 penalties	0.2	0.2	0.7	0.7	1.1	1.1	1.5	1.5	2.1	2.1	2.6	2.6
Total CJP-E3 penalties	0.3	0.4	0.9	1.0	1.4	1.5	1.9	2	2.6	2.7	3.1	3.2
Average control E penalty	0.233	0.267	0.767	0.800	1.200	1.233	1.633	1.667	2.267	2.300	2.767	2.800
relative change with only 0.1 point differences according to previous Case A (see shaded scores)		12.5%		4.2%		2.7%		2.0%		1.4%		1.2%
Penalties CV (%)	24.7	43.3	15.1	21.7	14.4	18.7	14.1	17.3	12.7	15.1	10.4	12.4
Maximum CV allowed for the Inter-judges' deductions for each range (%)	25		16.5		15		14.5		13.5		12.5	
Action required with regard to scores		Check		Check		Check		Check		Check		Check

Each routine was judged on its execution (E) and artistic merit (A), evaluated by a randomized pool of judges. Accuracy was measured as the deviation of a judge's E- and A-scores from the respective E- and A-control scores. Bias (integrity) was assessed by examining the rankings assigned by a judge for the exercises in a single round and across the entire competition. Consistency was evaluated by identifying unusual changes in the standard of marks given for the exercises (FIG, 2020). Paired panel and control scores were used to assess score accuracy (quantitative) and association concordance (ranking), for quantitative and qualitative evaluation, respectively.Lin’s Concordance Correlation Coefficient (LCCC) was used to measure the accuracy or concordance between each judge's score (Y) and the “true score” provided by the Control score (X) to quantify the agreement between these two measures) for the same gymnastic routine (Akoglu, 2018; Lin, 1989; McBride, 2005). The LCCC formula was as follows:

$$\rho_c = \frac{2s_{xy}}{S_x^2 + S_y^2 + (\bar{x} - \bar{y})^2}$$

where S_{xy} is the covariance, S^2 is the variance and $\bar{x}$ and $\bar{y}$ are the means for x and y raters,

$S_x^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2$, $S_y^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2$ and $S_{xy} = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})\,(y_i - \bar{y})$

Strength-of-agreement criteria for Lin’s concordance correlations coefficient were proposed as follows: <0.99 Almost Perfect, 0.95 to 0.99 Substantial, 0.90 to 0.95 Moderate and <0.90 Poor (McBride, 2005). However, for real competition, an acceptable range of deviation between judges’ scores is defined in Table 2.

This difference varies depending on the level of the competitive routine and is determined by the number of penalties awarded for technical and artistic errors. We assumed that the interpretation of correlation coefficients varies significantly across research areas. In gymnastics evaluation, due to potential inter-judge variability, particularly when penalties are greater, we proposed an interpretation closer to Altman's, suggesting that the strength-of-agreement criteria for Lin's concordance should be aligned with other correlation coefficients, such as Pearson's, where < 0.2 is considered poor and > 0.8 is excellent (Akoglu, 2018).

For ACROAJIR®'s assessment of acrobatic gymnastics judges’ performance, we defined Lin's concordance qualitative ranking criteria as: < 0.95 Excellent; 0.8 to 0.9499 Very Good; 0.7 to 0.7999 Good; 0.6 to 0.6999 Satisfactory; 0.5 to 0.5999 Poor; and less than 0.5 Very Poor. Additionally, we needed to measure the extent to which judges rank gymnastics routines in the correct order. Concordance and accuracy are crucial, and while small inter-score differences may be acceptable, the most important factor is ensuring that the final ranking is fair. To calculate judges' integrity, we used the strength of association between the judge and control rankings for each routine, applying the Kendall Concordance Coefficient (W).

Kendall’s W, which includes the presence of ties, was calculated as follows (Kendall & Babington-Smith, 1939; Wallis, 1939):

$$\mathrm{W} = \frac{12 \cdot \mathrm{S}}{\mathrm{m}^2(\mathrm{n}^3 - \mathrm{n}) - \mathrm{m} \cdot \sum_1^{\mathrm{m}} \mathrm{T_j}}$$

where m = number of raters, n = number of evaluated routines,

$$S = \sum_{i=1}^{n}(R_i - \bar{R})^2,$$

being R_i the sum of the ranges of the scores given by m evaluators to the ith subject and $\bar{R}$ is the arithmetic mean of the Ri, i = 1,…, n.

$$T_j = \sum_{i=1}^{g_j}(t_i^3 - t_i),$$

assigns the average of the rankings to the tied observation, where t_i is the number of tied values in the i-th grouping of ties, and gj is the number of tie groups in the j-th set of hierarchies, j = 1, ..., m.

Kendall’s W values lie between 0 and 1, where 0 indicates the absence of agreement, and 1 represents total agreement. A high Kendall’s W indicates that judges are likely to apply the same standards when evaluating the same competitive routines. As all switched ranking positions don't have the same relevance, the ranking swap costs vary. We proposed different Kendall's W reduction coefficients, according to the relevance of Judge and Control ranking positions being switched. When the relevance of the changed position increases, the coefficient that multiplies the value of Kendall's W decreases, and thus decreases the degree of agreement between judge and control. The different Kendall's W reduction coefficients are defined as follows: 0.7, 0.6, 0.8, 0.65, 0.82 and 0.75 when switching the 1vs3, 1vs4, 2vs3, 2vs4, 3vs4 and 3vs5 or more ranked positions, respectively.

To evaluate the qualitative ranking criteria for judges' performance, the final Kendall's W values were classified as follows: <0.95 excellent; 0.9 to 0.9499 very good; 0.8 to 0.8999 good; 0.7 to 0.7999 satisfactory; and 0.6 or less very poor.

These formulas were integrated into the ACROAJIR® spreadsheet, and a second macro function called "AJIR-macro" was developed. This macro used all the previously collected official E- and A-individual judges' scores, along with the revised control scores, to automatically and individually check all the predefined statistical and mathematical criteria. It was implemented to automatically analyze, generate, and export all the information presented in each individual report.

For each competitor and competition session, the report provides information about the execution or artistic score, the ranking assigned by each judge, and its relationship to the Control-and-Panel score and ranking, presented both numerically and graphically. If a judge's score deviation for a particular country exceeds the limit allowed by the FIG, a yellow alert is automatically displayed under the affected country in the score graph. If this difference impacts the rankings according to the criteria outlined in Table 1 and Table 2, the same yellow alert principle is applied.

The bias score compares a judge's score for their own country with the equivalent control score. If the judge-vs-control score or ranking deviation is more favorable to the judge's country than the defined allowable deviation, the score or ranking bias box will display a red alert. A quantitative and qualitative individual score and ranking evaluation was also included, using LCCC and Kendall's W values, to provide quick and understandable feedback on judges' performance.

Finally, the report presents a summary of all four E/A judges' panel evaluations. The ACROAJIR® "AJIR-macro" processes all the statistical and mathematical data to create and name each individual report. All data analysis was performed using an Excel spreadsheet (Microsoft, version 365-2019, US).

We collected data from 76 experienced international acrobatic gymnastics judges, who officiated at four official events during the 2017–2022 Olympic cycle: the 10th and 11th European Age Group Acrobatic Gymnastics Competitions (EAGC) and the 29th and 30th European Acrobatic Gymnastics Championships (ECh) held in 2019 and 2021, respectively.

To evaluate whether daily feedback on each judge's results improved their subsequent performance (in terms of accuracy and agreement with control scores) as the event progressed, each competition was divided into two parts. The first part was completed when either all judges had judged at least once or half of the competitive session had been finished. The second part encompassed all remaining competitive sessions. Judges evaluated routines approximately 3.25 ± 0.7 times in the EAGC and 4.05 ± 0.8 times in the ECh during each part. Each judge was evaluated at least once in each part.

Table 2.
Score and Ranking evaluation criteria defined between judges and control rankings. Higher differences generate a red or yellow highlighted alert.

Score evaluation criteria

Control score between		Allowed deviation
min	**max**	**judge vs Control**
9.5	10.00	0.1
8.7	9.499	0.2
8.0	8.699	0.3
7.0	7.999	0,4
6.0	6.999	0.5
5.0	5.999	0.7
0.0	4.999	1.0

Ranking evaluation criteria

Ranking positions intervals	Ranking differences between control and judge's rRanking
1st and 2nd	0 or 1 If the control score between 1st and 2nd place is greater than or equal to 0.1 point, then the difference in ranking with the control scores can be 1 place.
3rd and 4th	1
5 to 8th	2
9 to 12th	3
12th or more	4

Only competitive sessions with 6 or more competitors were used to assess judges to avoid small differences in scores causing large disparities in rankings and potentially resulting in unfair evaluations. With 6 or more competitors, the validity of the judges' evaluations improves. Since the final competition in the second part of EAGC events could only be assessed by higher-category judges, which might act as a confounding variable, we only included the qualification routines for EAGC. For the ECh event, both qualification and final competitive routines were included.

The intervention was designed to minimize significant inconsistencies in judging from one day or group to the next. Such inconsistencies were largely reduced, except for individual finals at ECh (balance or dynamic exercises). In these cases, it would require that the same judge be selected for the same role after a random draw. It is impossible for a judge to act in the same role for the same routine they had judged in qualifications at the EAGC, and it is limited to a pool of a few high-category judges at the ECh.

The independent variable was the performance in two parts of each competition event, while the dependent variables were changes in score accuracy and ranking concordance. Individual reports were sent after the completion of the 10th EAGC and 29th ECh events, without daily feedback conditions (NFBC). In contrast, for the 11th EAGC and 30th ECh events, individual reports were provided daily, within a maximum of 12 hours after the end of each competition day and before the next day’s session began, under daily feedback conditions (FBC). We compared a total of

953 reports: 272 from the EAGC and 680 from the ECh competitions.

Daily, after each competition, the control jury received all scores and validated their own accuracy in judging. The control scores validity macro quickly identified any significant differences between individual control judges' scores for all evaluated sessions. If significant differences were detected, the affected competitive routine was re-judged using video recordings at the end of each day's last competitive session to provide a more reliable true score within the defined deviation.

Once all control judges' scores were finalized, paired judge-and-control scores were obtained for accuracy (scores) and concordance (ranking) using the AJIR macro, which generated an individual report for each judge. A total of 1280 reports were created and sent confidentially. The computer used for this analysis was a Microsoft Surface Pro 7, 12.3" (Intel Core i5-1035G4, 8GB RAM, 256GB SSD, Microsoft, Redmond, USA). To analyze the effects of judging performance, we compared judges' performances between the first and second parts of each event, noting that daily evaluation reports were provided only for the 11th EAGC and 30th ECh events.

Standard statistical methods were used to calculate means and confidence intervals for accuracy and consistency, as previously defined. The Kolmogorov-Smirnov and Levene tests assessed normality and homogeneity of sample distributions. Data were analyzed using parametric or non-parametric tests based on these results.

Since each judging panel was drawn randomly, an unpaired t-test was used to evaluate the effects of prospective judging quality between the first and second parts of each event. Significance was set at $P \leq 0.05P \leq 0.05$. All analyses were conducted using SPSS software version 23.0 (SPSS, Chicago, IL).

RESULTS

Figure 1 illustrates the effects of prospective judging performance between the first and second parts of each event. Inter-judge performance was significantly higher in the 2021 (FBC) compared to the 2019 (NFBC) European ACRO events, with score accuracy improving from 0.75 ± 0.14 to 0.78 ± 0.15 ($p = 0.044$) and ranking concordance improving from 0.80 ± 0.13 to 0.82 ± 0.14 ($p = 0.007$). Judges' ranking concordance significantly improved when daily evaluations were provided (0.82 ± 0.13 vs 0.77 ± 0.19; $p = 0.000$), while score accuracy improved but not significantly (0.75 ± 0.16 vs 0.76 ± 0.17; $p = 0.305$).

Within events, judges' overall accuracy was significantly better in qualification competitions at the 11th EAGC compared to the 10th EAGC (0.76 ± 0.11 vs 0.80 ± 0.11; $p = 0.007$), with 160 vs 192 AJIRs, respectively. Judges' performance in ranking concordance significantly improved in the 30th ECh compared to the 29th ECh (0.76 ± 0.21 vs 0.82 ± 0.14; $p = 0.007$), with 368 and 320 AJIRs, respectively.

Comparing judging of execution and artistic performance in the first and second parts of competition events, the 10th EAGC (NFBC) showed a significant reduction in score accuracy differences for execution in the second part (0.80 ± 0.073 vs 0.72 ± 0.18; $p = 0.013$). Although judges' ranking concordance was lower in the second part (0.84 ± 0.10 vs 0.82 ± 0.13; $p = 0.446$), the difference was not significant. For artistic performance, there was no significant reduction in score accuracy differences in the second part (0.74 ± 0.10 vs 0.70 ± 0.15; $p = 0.221$), but there was a significant reduction in ranking concordance differences (0.77 ± 0.13 vs 0.70 ± 0.06; $p = 0.039$).

For the 29th ECh (NFBC), no significant differences in judges' accuracy for execution and artistic performance were found between the first and second parts of the competition. However, there was a significant reduction in judges' ranking concordance in the second part for execution (0.83 ± 0.15 vs 0.75 ± 0.27; p = 0.027) and artistic performance (0.76 ± 0.12 vs 0.71 ± 0.25; p = 0.043).

In the FBC, at the 11th EAGC, judges' concordance for both artistic and execution scores improved in the second part of the competition for accuracy and ranking, with significant differences observed only for execution accuracy (0.83 ± 0.13 vs 0.70 ± 0.07; p = 0.017). At the 30th ECh (FBC), the only significant increase in judges' score accuracy was for artistic performance (0.63 ± 0.23 vs 0.73 ± 0.18; p = 0.005).

A total of 1280 individual reports were created and analyzed at the end of each competition day, but only 640 were sent confidentially for the 2021 events. For easier understanding by the judges, the accuracy and concordance values in the individual reports were multiplied by 100 (Figure 2).

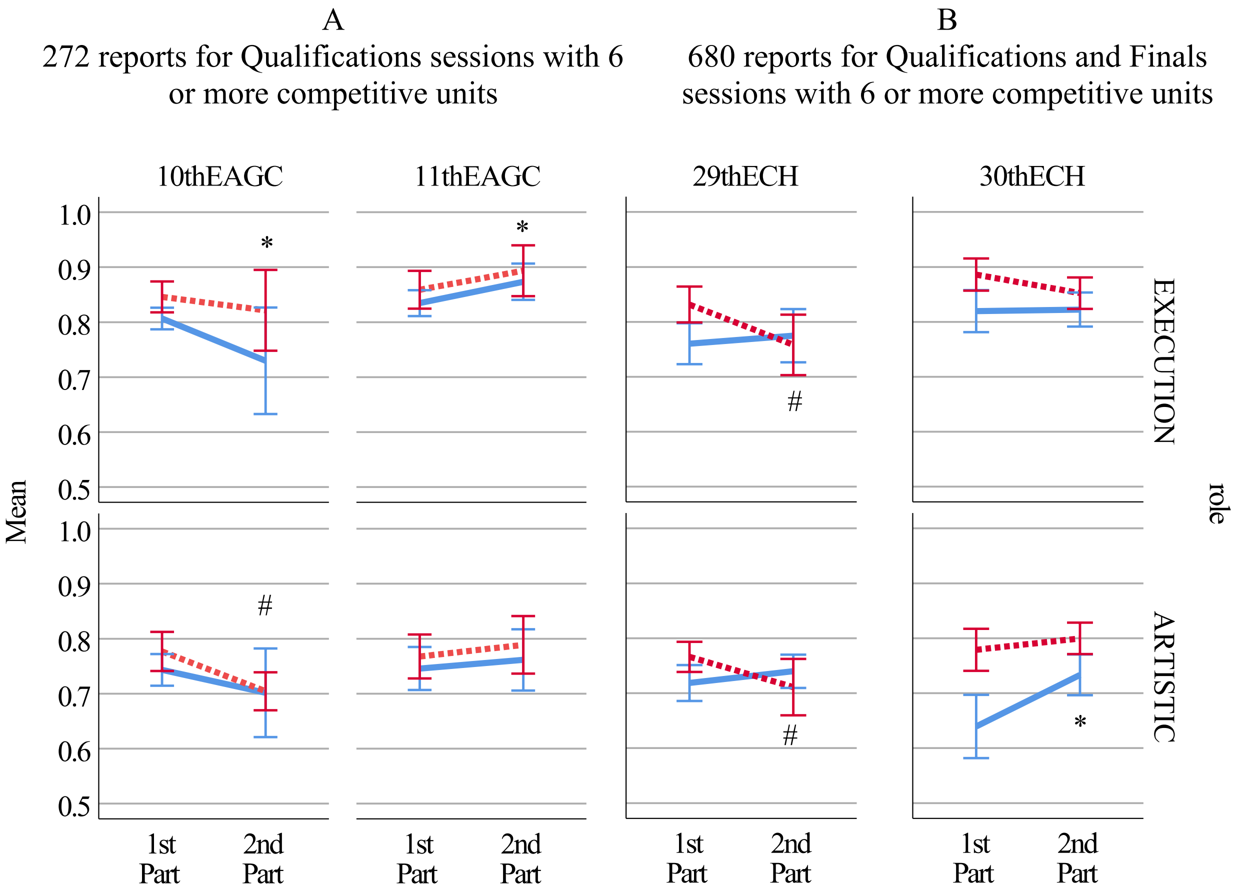
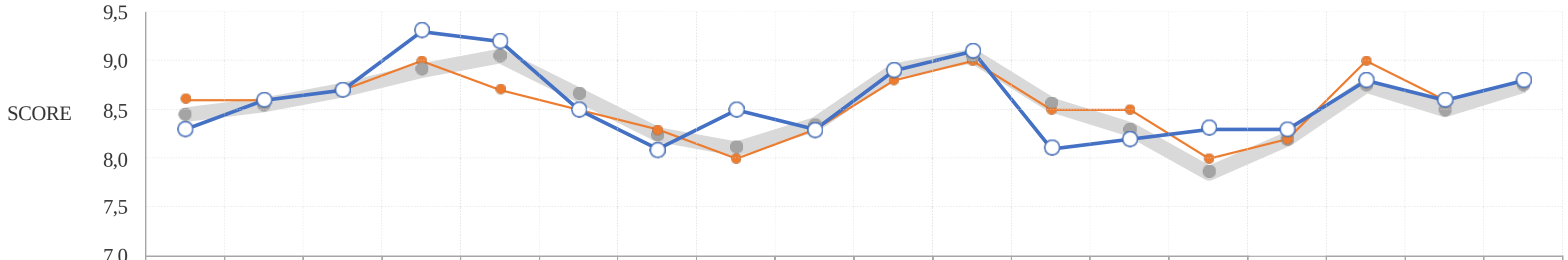


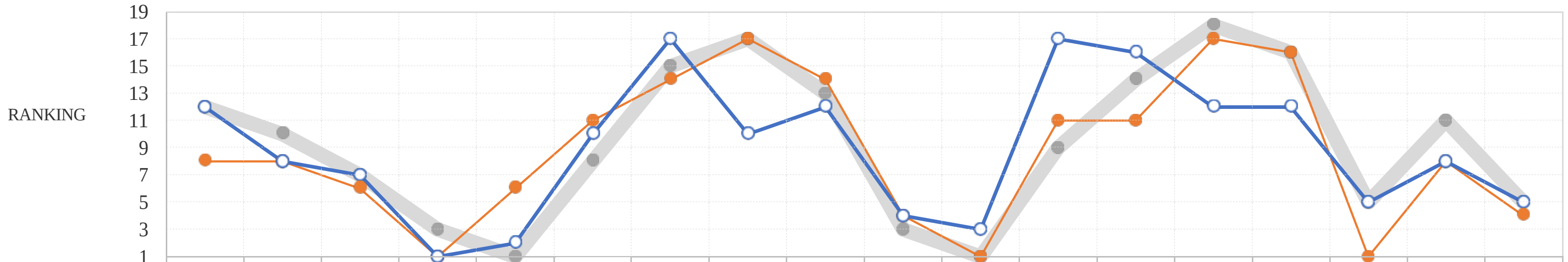
Figure 1. Mean and 95% confidence intervals for score accuracy (bold line) and ranking (dashed line) judges' evaluations for artistic performance or execution in the first and second parts of EAGC (A) and ECh (B) events (* p<0.05 score significant differences; # p<0.05 ranking significant differences).



	MDA	ESP	GBR	NOC	ESP	POR2	FRA	GEO	SUI	POR1	RUS	AZE2	IRL	BUL	POL	AZE1	HUN	UKR
Score	8,45	8,55	8,70	8,90	9,05	8,65	8,25	8,10	8,35	8,90	9,05	8,55	8,30	7,85	8,20	8,75	8,50	8,75
Control-SCORE Execution	8,60	8,60	8,70	9,00	8,70	8,50	8,30	8,00	8,30	8,80	9,00	8,50	8,50	8,00	8,20	9,00	8,60	8,80
E1 NOC Judge E Name	8,30	8,60	8,70	9,30	9,20	8,50	8,10	8,50	8,30	8,90	9,10	8,10	8,20	8,30	8,30	8,80	8,60	8,80

Warning for SCORE

Bias for SCORE



	MDA	ESP	GBR	NOC	ESP	POR2	FRA	GEO	SUI	POR1	RUS	AZE2	IRL	BUL	POL	AZE1	HUN	UKR
Ranking E Score	12	10	7	3	1	8	15	17	13	3	1	9	14	18	16	5	11	5
Control Execution Ranking	8	8	6	1	6	11	14	17	14	4	1	11	11	17	16	1	8	4
E1 NOC Judge Name	12	8	7	1	2	10	17	10	12	4	3	17	16	12	12	5	8	5

Warning for RANKING

E1 NOC Judge Name Evaluation

The accuracy and consistency of your judging were			BIAS
SCORE	72%	Good	YES
RANKING	84%	Good	NO

E PANEL Evaluation

The accuracy and consistency of your judging were		
SCORE	77%	Good
RANKING	78%	Satisfactory

Figure 2. An example of individual reports in one competitive session. Session and judge data are hidden to protect confidentiality. (Wide bright line: Panel score; Thin line with filled circles: Control score; Bold line with empty circles: Judge score

DISCUSSION

The aim of this study was to design and apply the ACROAJIR® tool to control and evaluate ACRO judges' performance and prospective judging effects at major competitive events. The tool had practical applications in three domains: a) a specific Technical Committee (TC) control task; b) feedback for individual judges; and c) assessment of prospective judging effects.

Fulfilling a specific TC control task, the ACROAJIR® results provided the Technical Committee (TC) with an overview of results and specific, objective information about judges' performance in each competitive session. This information facilitated easy, quick, and accurate identification of individual judges' mistakes. It offered strong evidence for managing these mistakes, supporting correct decision-making, and alerting judges to potential future issues. TC members received objective data on the accuracy, concordance, and bias of judges' scores.

Performance feedback is commonly used to influence behavior, and providing information about past performance is a widely adopted strategy in competitions. However, the effects of daily performance feedback have not been previously evaluated. This quantitative study analyzed how daily feedback, supported by the AJIRs-based formative assessment process, affected judges' accuracy and concordance. Each judge received a simple daily report on their performance in terms of accuracy and concordance at the 2021 competition events, and those with the best scores were congratulated. Knowledge of the control score enhanced judges' self-confidence and consistency by providing an objective assessment of their accuracy, consistency, and concordance relative to the control score. None of the judges disagreed with the reports received, and all appreciated the daily feedback effort. No prior studies with similar designs were found.

Knowing that they would be evaluated daily appeared to motivate judges to consistently perform their best. The effects were differentiated based on whether feedback was provided daily or not, particularly for characteristics such as score accuracy and concordance.

Feedback included comparisons with benchmarks beyond the in-competition trimmed mean. Overall, judges' performance significantly improved when they were aware of daily evaluations. Specifically, judges' score accuracy was significantly better with daily reports at the 11th EAGC, and ranking concordance was better at the 30th ECh. While judges knew they would be evaluated at the start of each competition, they did not anticipate receiving daily reports.

Overall, judges' performance was significantly worse in the second part of competitions where no feedback was given, compared to when they received daily feedback, which either maintained or improved performance. Significant declines were observed in execution accuracy scores and artistic ranking concordance at the 10th EAGC (NFBC) and in artistic ranking concordance at the 29th ECh (NFBC) during the second parts of these events.

In contrast, with daily feedback conditions (FBC), both accuracy and ranking concordance improved in the second part of the competition for both artistic performance and execution at the 11th EAGC. At the 30th ECh, judges' score accuracy for artistic performance was significantly higher.

Previous studies examining judges in gymnastics, judo, rope climbing, and synchronized swimming found that when judges received open feedback (i.e., the ability to hear or see their colleagues' scores after each performance), the variation between scores was significantly lower. This suggests that conformity was influenced by informational factors (Auweele et al., 2004; Boen et al., 2006, 2008, 2013), which supports our findings.

However, reference panel scores can sometimes be incorrect, potentially influencing a judge's decisions. This normative conformity bias can be dangerous and lead to unfair results. Even if a judge's score is accurate, consistently aligning with the panel's score when deviations occur can compromise judgment, leading to normative conformity bias. Daily feedback on control scores mitigates this risk by boosting judges' confidence in their own judgments, thereby motivating better performance in future sessions.

In summary, judges' performance either remained stable or improved when they were consistently updated on their performance. Overall, higher score accuracy was associated with greater ranking concordance. However, when routines were at a similar level, small changes in score accuracy led to significant changes in ranking concordance. This assessment proved valuable for detecting instances where judges might exploit small but permissible scoring gaps to favor their own countries. It also provided feedback on judges' scoring patterns, which could be useful for training and accrediting judges. Updates and feedback can help propose corrective measures for judges who perform below expectations (Mercier & Heiniger, 2018).

Judges aim to perform at their best, and the results demonstrated a high level of quality overall. Although a consistently high performance might limit improvements as the event progresses, knowledge of daily evaluations during the 2021 events led to significantly more accurate scores as the competition continued. This article introduces a novel approach to evaluating judges' performance during live competitions. To our knowledge, providing individual written feedback reports during competitions has not been previously implemented. This method suggests new active methodologies and formative evaluations for future use.

The current study had several limitations. First, the use of expert superior jury scores as 'true' scores introduces potential issues, as these expert scores might also be inaccurate or not align with the judging panel. This could affect the evaluation of judges during live competitions. The ranking swap costs defined in this study might be better represented by more sophisticated regression equations to explain all relevant ranking swap cases. Additionally, refining the definitions for the first and second periods and using the tool solely for pedagogical purposes, without sanctions for biased or incorrect judgments, could impact the number of significant differences observed in judges' performance as the events progressed. Although post-feedback improvements in accuracy were noted, understanding the process behind this alignment would provide insights into the cause of discrepancies. Future research should include more examples to validate the findings of this study. With more comprehensive evidence, further actions can be taken to enhance the rating system for the discipline (Anderlucci et al., 2020).

CONCLUSION

The ACROAJIR® tool offered timely, valuable, and personalized feedback on accuracy and concordance scores for acrobatic gymnastics judges during competitions. It demonstrates that such feedback can be effectively delivered during, rather than only after, competition events. The tool facilitates specific TC scoring control tasks, provides judges with evidence-based feedback, and suggests targeted improvements for prospective judging.

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ANALYSIS OF THE PERCEPTION OF BODY IMAGE IN FIT KID ATHLETES

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Abstract

The aim of this research was to analyze the degree of dissatisfaction with body image—defined as the dissatisfaction resulting from the difference between the desired silhouette and the perceived one—among Fit Kid athletes. The study compared data based on age ranges and levels of competition and examined the possible association between higher weight and BMI with increased concern for body image. The Body Shape Questionnaire (BSQ) was used, and data were analyzed using the SPSS 28.0 statistical package. The main findings reveal a higher degree of body image dissatisfaction at the highest level of competition (national level) and among athletes with higher BMI and weight. Specifically, the factor with the highest scores was body dissatisfaction with the lower body. This suggests a higher risk of body image issues in late adolescence and at higher competitive levels, as well as among athletes with higher BMI values. These findings could offer valuable insights for coaches, who might address these issues through collaboration with nutritionists and sports psychologists.

Keywords: *body dissatisfaction, leanness, competition level, BMI, aesthetic disciplines*

INTRODUCTION

Body image perception is defined as ‘the image our mind forms of our own body, that is, the way our body manifests itself to us’ (Schilder, 2013, p. 11) and is directly related to eating disorders (Torres et al., 2017). Eating disorders are a group of mental illnesses characterized by abnormal eating behaviors, along with behaviors or attitudes aimed at weight control (Sadock, Sadock & Ruiz, 2015). These disorders generally occur in adolescents and young adults, with prevalence studies indicating wide differences according to age group and gender, being much higher in young women. Among the most common or prevalent eating disorders in Europe are anorexia nervosa and bulimia nervosa (Arija, Santi, Novalbos, Canals & Rodríguez, 2022). As for the age of onset, anorexia nervosa typically begins ate around 12 to 13 years, while bulimia nervosa starts between 14 and 15 years (Keski-Rahkonen et al., 2007).

As mentioned above, this preoccupation with weight gain and obsession with eating is also linked to a factor that characterizes this type of disorder: dissatisfaction with one's own body image (Torres et al., 2017). This is understood as the dissatisfaction resulting from the difference between the perception of the desired silhouette and the perceived silhouette (Jiménez, Jiménez & Bacardi, 2017).

The most common stages of onset of these problems are early and middle adolescence, though they can develop in children as young as 6 years old (Swanson, Crow, Le Grange, Swendsen & Merikangas, 2011). Regarding incidence in sport, a relationship can be established between aesthetic sports and dissatisfaction with body image, which is considered a risk factor for the development of dangerous eating behaviors, such as anorexia (Valles, Hernández, Baños, Moncada-Jiménez & Rentería, 2020), in female athletes in this types of sport disciplines (Fortes, Neves, Filgueiras, Almeida & Ferreira, 2013). Among dancers and gymnasts, risky methods to achieve a specific body typology, such as pressure to be thin and follow dietary restriction, are observed (Francisco, Alarcão & Narciso, 2012). Similarly, in sports that emphasize thinness, there are higher levels of body image dissatisfaction and more symptoms of eating disorders, with even higher rates found among elite athletes, regardless of whether they participate in aesthetic sports (Kong & Harris, 2014). Even among children who practice aesthetic sports, there is a quest to be thinner, despite already having lower body weights compared to children who participate in other types of sports (Lombardo, Battagliese, Lucidi & Frost, 2012). Additionally, girls aged 5 and 7 years who practice aesthetic sports show greater concern about weight compared to girls who practice non-aesthetic sports or who do not practice sports at all (Davison, Earnest & Birch, 2002). Adolescent gymnasts also exhibit greater body dissatisfaction than adolescent non-gymnasts (Valles et al., 2020).

In this sense, the risk of presenting a greater concern about body image is much higher among gymnastics disciplines due to the strict attitude towards weight and shape, which can become an obsession (Bloodworth, McNamee & Tan, 2017). Adolescent gymnasts may be even more vulnerable to developing such problems, as the body image concerns and insecurities common at their age are reinforced by the pressure to achieve or maintain a particular body shape and weight in order to compete at the highest level of the sport (Tan, Bloodworth, McNamee & Hewitt, 2012).

Several studies in recent decades have linked gymnastics and dance to high body image dissatisfaction and eating disorders among athletes and dancers (Bloodworth et al., 2017; Francisco et al., 2012). For example, in artistic gymnastics, female gymnasts appear to be at higher risk of developing eating disorders than male gymnasts (Papacharalampous, Dallas & Dallas, 2022), as it is common for gymnasts to experience a high degree of body image dissatisfaction, which increases during the competition season (Neves et al., 2016). Rhythmic gymnastics is considered the gymnastic discipline with the highest risk of its practitioners suffering from eating disorders compared to other disciplines such as artistic gymnastics or acrobatic gymnastics, probably due to the pressure in rhythmic gymnastics to obtain a very slim body, the perfectionist tendencies of the discipline (Nordin, Harris & Cumming, 2003), and the excessive weight control and emphasis on low adipose mass for success in performance (Palacios & Sánchez, 2016). Furthermore, a high-level gymnast not only needs to possess certain physical aptitudes, but her body composition is also a determining factor for success, providing the biomechanical characteristics necessary for the execution of the exercises (Márquez, 2008; Palacios & Sánchez, 2016). This situation can lead to a certain risk of disordered eating behaviour in the pursuit of results, particularly in maintaining a low weight and slim appearance (Palacios & Sánchez, 2016), with more cases occurring among rhythmic gymnasts at a higher level, such as the international level, than among gymnasts at non-competitive levels (Donti, Donti, Gaspari, Pleksida & Psychountaki, 2021; Kontele, Vassilakou & Donti, 2022).

Fit Kid, an emerging sport created in Europe in 1990 and part of the Spanish Federation of Dance Sport, combines gymnastic elements with dance, creating a significant artistic component. It requires certain physical qualities such as flexibility, strength, and endurance, as well as rhythmic and artistic qualities like coordination and body expression (Paredes, n.d.). This sport includes individual and group participation categories, with group categories being further divided into duos, small groups (3 or 4 members), and large groups (5 or 6 members). These group categories are divided into three competition age groups (7-11 years; 12-15 years; 16 years and over). Additionally, there is a free large group category, where 7 to 15 athletes can participate with no age restrictions. In the group categories, the gender of the competitors is unrestricted. Participants in all age categories must perform a floor choreography accompanied by music, including compulsory elements specified in the scoring code (Fit Kid scoring code, 2023). In this way, Fit Kid resembles and draws from both gymnastic disciplines and dance, adapted to Fit Kid's unique characteristics.

Given the existing link between Fit Kid and gymnastic disciplines, we question whether athletes in this sport might also manifest or develop a similar tendency toward high dissatisfaction with their own body image. Under these premises, the aim of this research was to analyze the current state of body image perception among Fit Kid athletes, comparing the established age ranges and the varying levels of competition—specifically, first-class and second-class levels. Additionally, the research sought to identify the type of association between higher weight and BMI with a more pronounced concern for body image.

METHODS

This descriptive research with a quantitative approach was conducted using a purposive sample. The sample was selected based on the following inclusion criteria: Fit Kid athletes from clubs in a municipality in the province of Alicante (Spain), male or female, with a valid federation license, at first-class or second-class levels, and within the age range of 11 to 24 years, as federation licenses were available for athletes up to this age range. After applying these criteria, the total population meeting these characteristics was 80 athletes, of which 14 were excluded for not obtaining the corresponding informed consent.

Therefore, in the end, 66 athletes between 11 and 19 years of age (62 women and 4 men), belonging to 5 Fit Kid clubs in the municipality in question, participated voluntarily. The sample obtained represents 82.5% of the total population studied, with a mean age of 13.42 ± 1.84 years. Of the 66 participants, 19 were from the first-class level, representing 95% of the population for this level and age range, and 47 from the second-class level, representing 78.3% of the population for this level and age range. To facilitate the search for a relationship between age and the perception of body image, the sample was divided into three age ranges based on the three stages of adolescence (Güemes-Hidalgo, Ceñal & Hidalgo, 2017): the first from 11 to 13 years (12.28 ± 0.78), the second from 14 to 16 years (14.52 ± 0.68), and the third from 17 years onwards (18 ± 1).

To obtain the data, basic anthropometric techniques and tools were used to determine the participants' height, weight in kilograms, and to calculate their BMI. In addition, the Body Shape Questionnaire (BSQ) was administered in its Spanish adaptation (Raich, Mora, Soler, Clos & Zapater, 1996). This questionnaire consists of 34 questions with a Likert frequency scale, is self-administered, and has 6 response options (1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = very often, and 6 = always). The BSQ score ranges from 34 to 204 points, which is the sum of all the points obtained in each question, with a cut-off score of 105 points (Raich, 2001). Scores of 105 points and above indicate the presence of anxious, negative thoughts in the athlete, leading to dissatisfaction with their body image as it deviates from their ideal body model. This dissatisfaction often results in lower self-esteem related to physical appearance and a desire to lose weight and diet, leading to an extreme preoccupation with figure and weight. All these factors place the athlete at risk of developing an eating disorder.

Furthermore, the 34 items are grouped into five factors:

- Factor 1: concern about weight in relation to intake (items 6, 23, 17, 21, 2, 14 and 19).
- Factor 2: concern about unsightly aspects of obesity (items 28, 30, 5 and 16).
- Factor 3: general body dissatisfaction and concern (items 7, 18 and 13).
- Factor 4: lower body dissatisfaction (items 3 and 10).
- Factor 5: use of vomiting or laxatives to reduce body dissatisfaction (items 26 and 32).

To begin the research, the team first contacted the coaches of the Fit Kid clubs in the municipality involved by telephone to arrange visits. Next, the study's objectives, a description of the questionnaire and the measurements to be taken, the characteristics and criteria to be met by the athletes, and the process to be followed were explained. The athletes were also informed about the aims of the research, with an emphasis that their participation was voluntary and without any form of compensation. Upon confirming their agreement, informed consent was obtained from the legal representatives and athletes of legal age. Simultaneously, respect for data protection regulations in accordance with the Declaration of Helsinki was ensured, guaranteeing the anonymity of the athletes.

Data collection took place between 22 March and 13 April 2023, during the athletes' competitive period. This period was chosen as there tends to be greater pressure to perform well in training and to achieve good results in competition, making the information obtained particularly relevant to these phases of training. On the specified days and at the indicated clubs, the athletes were grouped together, and the questionnaire was completed either online or on paper. In both formats, a series of descriptive data (age, sex, and level of competition) was included at the start, followed by the BSQ questionnaire. Athletes spent 10-15 minutes completing the BSQ and then proceeded to measure body mass (using a Renpho digital scale, accurate to 0.05 kg) and height (using an Alfa measuring rod, accurate to 1 mm) to calculate their BMI (kg/m²). The measurement of body mass and height was conducted in the presence of their coaches and one of the authors of this work to clarify any doubts. Measurements were taken with the athletes barefoot, standing with their feet parallel and heels together, fully erect. The head, shoulders, and buttocks were in contact with a vertical plane (wall). For the weight measurements, the athletes were barefoot and wore their own training clothes (leotard).

The specialized software SPSS (Statistical Product and Service Solutions), version 28.0.0.0 (190) from IBM, was used for data analysis. Descriptive statistics, including means, medians, standard deviations, and cross-tabulations, were used to analyze the data. Correlations between BSQ scores and age, weight, BMI, and competition level were assessed using Spearman's correlation, while comparisons between the two competition level groups were analyzed using the Mann-Whitney U test, with a significance level set at $p \leq 0.05$. Finally, the internal consistency of the instrument, measured by Cronbach's Alpha, was found to be adequate (0.962), as this value is above the minimum established range (0.90-0.95), indicating good internal consistency (George & Mallery, 2003).

RESULTS

Firstly, regarding the descriptive data (Table 1), the average weight of the athletes was 48.31 kg, the average height was 1.55 m, and the average BMI was 19.9 kg/m². The highest averages for weight, height, and BMI are found in the third age range and at the second-class level, with significant differences between levels only for height ($p = 0.027$). Conversely, the lowest averages for weight, height, and BMI are found in the first age range and at the national competition level.

Regarding the sample's score on the Body Shape Questionnaire, the mean score was 67.44 points, which is below the cut-off score, indicating a low general concern for body image (Table 1). However, this concern increases with age and is considered mild for those aged 17 years and older. As for the comparison between competition levels, a slightly higher score is observed at the first-class level, but without significant differences (p = 0.197) (Table 1).

Table 1
Weight, height, BMI and BSQ scores of Fit Kid athletes according to age range and competition level

	Total	**11-13**	**14-16**	**+17**	**First-class**	**Second-class**	**Level U-test**
	M (SD)	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	***p***
Weight (kg)	48.31(8.00)	45.01(7.26)	51.81(7.70)	56.04(3.12)	45.61(6.64)	49.40(8.30)	0.095
Height (m)	1.55(0.07)	1.54(0.07)	1.57(0.07)	1.60(0.05)	1.53(0.05)	1.56(0.08)	**0.027**
BMI (kg/m²)	19.90(2.27)	19.10(2.10)	20.95(2.15)	21.95(0.59)	19.45(1.88)	20.08(2.40)	0.492
BSQ	67.44(27.58)	59.58(23.94)	73.14(27.22)	104.40(19.49)	72.58(23.64)	65.36(29)	0.197

Note: M-mean; SD-standard deviation; *p*-significant differences between levels

The correlation study shows a moderate, positive, and direct association between weight and BMI with the BSQ scores (Table 2), and this correlation is statistically significant (p<0.01).

Secondly, regarding the results associated with body shape (BSQ) according to the analysis factors (Table 3), the greatest concern is observed in the third age range for all factors. Additionally, when focusing on the level of competition, greater concern is noted at the first-class level for factors 1, 2, and 3, and at the second-class level for factors 4 and 5. However, no statistically significant differences are observed between the levels in any of the factors, with factor 1 approaching the level of significance (p = 0.058).

Table 2
Correlations of BSQ scores

	Age	**Age range**	**Weight**	**BMI**	**Level**
BSQ	0.456**	0.393**	0.477**	0.477**	0.160

Note. **p<0,01; *p<0,05

It is also noteworthy that factor 4, "Body dissatisfaction with respect to the lower part of the body," has the highest mean score. This indicates that dissatisfaction with self-image among the athletes is most pronounced concerning the lower part of their body. Conversely, factor 5, "Use of vomiting or laxatives to reduce body dissatisfaction," has the lowest mean score, suggesting that, in general, Fit Kid athletes did not use these compensatory method.

Table 3
Mean of the factors according to age range and competition level

Factor	Total	11-13	14-16	+17	First-class	Second-class	Levels U-test
	M	M	M	M	M	M	*p*
1. Concern about weight in relation to intake	2.06	1.78	2.23	3.63	2.36	1.94	0.058
2. Concern about unsightly aspects of obesity	1.98	1.70	2.07	3.85	2.13	1.92	0.361
3. General body dissatisfaction and concern	1.62	1.36	1.94	2.40	1.72	1.58	0.143
4. Lower body dissatisfaction	2.14	1.95	2.34	2.80	2.03	2.18	0.896
5. Use of vomiting or laxatives to reduce body dissatisfaction	1.06	1.02	1.05	1.40	1.03	1.08	0.478

Note: M-mean; *p*-significant differences between levels

Finally, regarding the results that show significant differences between levels (Table 4), we note in factor 1, "Concern about weight in relation to intake," that item 17, "Eating sweets, cakes, or other high-calorie foods—has it made you feel fat?" (p = 0.036) and item 19, "Have you felt excessively fat or rounded?" (p = 0.043) show significant differences. Additionally, values close to the pre-specified significance level are observed in item 14, "Being naked (e.g., when you take a shower)—did it make you feel fat?" (p = 0.065) and item 21, "Worrying about your figure—did it make you go on a diet?" (p = 0.053). On the other hand, in factor 3, "General body dissatisfaction and concern," item 13, "Has thinking about your figure interfered with your ability to concentrate (when watching TV, reading, or having a conversation)?" (p = 0.063) is close to the pre-specified significance level.

Table 4
Intake concerns according to age range and level of competition

Factor	Item	Total		11-13		14-16		+17		First-class		Second-class		Levels U-test
		Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	*p*
1	**2**	2.50	2.64 (1.50)	2	2.23 (1.37)	3	3.10 (1.51)	4	4 (1.23)	3	3 (1.33)	2	2.49 (1.55)	0.130
	6	2	2.26 (1.33)	1	2 (1.28)	2	2.43 (1.25)	3	3.60 (1.34)	3	2.58 (1.31)	2	2.13 (1.33)	0.153
	14	1	1.65 (0.94)	1	1.40 (0.71)	1	1.81 (1.08)	3	3 (0.71)	2	2 (1.05)	1	1.51 (0.86)	**0.065**
	17	2	2.35 (1.50)	1	2.10 (1.46)	2	2.33 (1.24)	4	4.40 (1.52)	3	2.79 (1.13)	1	2.17 (1.60)	**0.036**
	19	1	1.44 (0.79)	1	1.23 (0.48)	1	1.67 (1.11)	2	2.20 (0.45)	2	1.63 (0.76)	1	1.36 (0.79)	**0.043**
	21	1	2.08 (1.37)	1	1.75 (1.19)	2	2.19 (1.29)	4	4.20 (1.30)	3	2.58 (1.50)	1	1.87 (1.28)	**0.053**
	23	1	2.03 (1.46)	1	1.78 (1.39)	2	2.05 (1.24)	4	4 (1.58)	2	1.95 (1.08)	1	2.06 (1.59)	0.564
2	**5**	1.50	1.86 (1.07)	1	1.68 (0.89)	1	1.76 (0.89)	4	3.80 (1.30)	1	1.89 (1.10)	2	1.85 (1.06)	0.927
	16	2	2.14 (1.24)	1.50	1.75 (0.95)	2	2.29 (1.06)	5	4.60 (1.14)	3	2.42 (1.22)	2	2.02 (1.24)	0.150
	28	1	1.48 (1.09)	1	1.25 (0.59)	1	1.57 (1.25)	3	3 (2.12)	1	1.58 (1.35)	1	1.45 (0.97)	0.954
	30	2	2.42 (1.40)	2	2.10 (1.22)	3	2.67 (1.59)	4	4 (0.71)	3	2.63 (1.42)	2	2.34 (1.40)	0.371

Factor	Item	Total		11-13		14-16		+17		First-class		Second-class		Levels U-test
		Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	Me	M (SD)	*p*
3	7	1	1.92 (1.33)	1	1.55 (0.97)	2	2.48 (1.69)	3	2.60 (1.14)	1	2.05 (1.31)	1	1.87 (1.35)	0.503
	13	1	1.62 (0.99)	1	1.27 (0.72)	2	1.90 (1.09)	3	3.20 (0.45)	2	1.79 (0.79)	1	1.55 (1.06)	**0.063**
	18	1	1.32 (0.70)	1	1.25 (0.63)	1	1.43 (0.81)	1	1.40 (0.89)	1	1.32 (0.67)	1	1.32 (0.73)	0.894
4	3	2	2.24 (1.27)	2	1.90 (1.08)	3	2.62 (1.32)	3	3.40 (1.52)	2	2.32 (1.11)	2	2.21 (1.33)	0.550
	10	2	2.03 (1.12)	1	2 (1.22)	2	2.05 (1.07)	2	2.20 (0.45)	2	1.74 (0.73)	2	2.15 (1.23)	0.339
5	26	1	1.11 (0.40)	1	1.02 (0.16)	1	1.10 (0.30)	1	1.80 (1.10)	1	1 (0)	1	1.15 (0.47)	0.143
	32	1	1.02 (0.12)	1	1.02 (0.16)	1	1 (0)	1	1 (0)	1	1.05 (0.23)	1	1 (0)	0.116

Note: Me-median; M-mean; SD-standard deviation; *p*-significant differences between levels.

DISCUSSION

The main objective of this research was to analyze the current state of body image among Fit Kid athletes according to age ranges and competition levels (first and second class). Additionally, it aimed to identify the type of association between higher weight and BMI and greater concern for body image.

Firstly, with regard to the relationship between weight and BMI of Fit Kid athletes and a high score on the body image perception scale, we observed a moderate positive association between weight (r=0.477) (p=<0.01) and BMI (r=0.477) (p=<0.01) and a greater concern and dissatisfaction with body image among the athletes.

Regarding the perception of body image, Lombardo et al. (2012) related a sufficiently low or optimal weight with even more pronounced body dissatisfaction in children practicing aesthetic sports. They found that these children, who were already thinner than those participating in non-aesthetic sports or those not engaged in sports, wished to be even thinner. Similarly, Vernetta, Montosa, and Peláez (2018) observed that while acrobatic gymnasts generally showed good body satisfaction associated with a healthy BMI, 12.1% of rhythmic gymnasts expressed a desire to be even thinner. In contrast, Ariza, Salas, López, and Vernetta (2021) concluded that adolescent acrobatic gymnasts were more satisfied with their self-image than non-acrobatic gymnasts.

Also, in relation to age, the highest mean BSQ scores in the present study were found in the third age range (17 years and older), indicating a mild concern about body image. In the other age ranges, and in general, no significant body image dissatisfaction was observed. However, the association between age or age range and questionnaire scores was relevant, according to correlational studies.

In this sense, Little, Howell, Armento, McCarthy, and Sweeney (2023) found greater anxiety and concern about weight at older ages, as their research indicated that older gymnasts exhibited higher levels of concern. This increased body dissatisfaction in the older age range could be explained by the higher BMI values that occur with age during developmental growth (Maganto & Cruz, 2002), as age and BMI have a significant positive relationship (Vernetta, Peláez, Ariza & López, 2018), as observed in the present study. Additionally, a higher BMI may trigger a greater desire for thinness or lower satisfaction with body image (Maganto & Cruz, 2002). Conversely, this can result in a discordance between perceived BMI and actual BMI due to a distortion of body image, causing individuals who are underweight or at the lower limit of normal weight to overestimate their weight (Durán et al., 2013). Furthermore, a higher muscle mass (for the same height) results in a higher BMI, which contributes to dissatisfaction among many aesthetic sportswomen (Valles et al., 2020). Consequently, reduced intake often leads to low energy availability, which poses additional health risks for female athletes.

On the other hand, the association between BSQ scores and level of competition was low. Within this analysis, the highest scores were observed at the higher level of competition, indicating a more negative perception of body image. However, the differences between the two levels were not statistically significant.

Kong and Harris (2014) found that, at elite levels—regardless of the sport—and in thinness-focused sports, athletes more commonly exhibited symptoms typical of eating disorders, as well as a higher rate of preoccupation and lower satisfaction with self-image. Similarly, Salas, Gutiérrez, Ariza, and Vernetta (2023) observed this trend among Spanish acrobatic gymnasts, where international-level gymnasts showed higher rates of body dissatisfaction and a greater tendency towards thinness compared to athletes at other levels of competition.

In reference to the factors that caused the most concern among the athletes, there was a notable dissatisfaction with the lower part of their body, particularly regarding the thighs, buttocks, hips, and waist, including the measurements and proportions of these areas. This dissatisfaction was more pronounced on average from the age of 17 onwards but did not significantly differ between competition levels. The only significant differences between levels were observed in some items related to concerns about intake.

In this respect, Maganto and Cruz (2002) argued that the area of the body generating the least dissatisfaction in women was the face, while the upper and lower torso, and particularly the waist, caused much higher dissatisfaction. Their findings align with the present study, which identified the lower torso, and more specifically the thighs, buttocks, and hips, as focal points of significant concern and dissatisfaction with body image. Similarly, Salazar (2008) found notable dissatisfaction with various body parts, including the complexion, nose, chest, abdomen, waist, thighs, and legs, among adolescents of both genders, with a particular focus on dissatisfaction with the arms. Additionally, Salazar's study revealed that females were more concerned with areas such as the abdomen, legs, hips, thighs, and waist compared to males.

Among the limitations of the study, it is important to note the scarcity of research on the Fit Kid discipline and the significance of body image perception among its practitioners. Additionally, the sample size may be too small to fully represent the discipline in the province analyzed, as well as within the specific geographical context of the research. Other variables, such as the athletes' years of competitive experience, different training periods, and the profiles of coaches and technical staff, were not considered. These limitations should be taken into account when generalizing the results. Therefore, further research is needed to explore how body image perception evolves during different training periods and to examine potential differences in body image perception across various aesthetic sports.

CONCLUSIONS

The main conclusions drawn from the study are as follows: there is a positive association between BMI and BSQ scores, indicating that higher BMI and weight values are linked to greater body image concerns among Fit Kid athletes. Generally, higher levels of body image dissatisfaction were observed at the first-class level, the most demanding competitive level, highlighting the need to be vigilant about potential body image distortions that could lead to eating-related behavioral disorders. Lastly, the factor that caused the most concern among participants was 'Body Dissatisfaction Regarding the Lower Body.' This concern was slightly more pronounced in the third age range and at the second-class level, although no significant differences between levels were observed.

These results can be very useful for coaches of aesthetic sports in general and Fit Kid coaches in particular. Understanding the degree of body shape dissatisfaction among athletes can help detect potential risk situations for the development of eating disorders. Being aware of these issues would enable coaches to make informed decisions, such as focusing on psychological work aimed at improving self-concept and self-esteem.

In this regard, coaches could emphasize the importance of a balanced diet for overall health rather than focusing on athletes' physical appearance. This includes avoiding negative comments about weight or the pressure to achieve an excessively thin physique, which could negatively impact the athlete. Additionally, promoting training seminars for coaches on these issues, including their symptoms and health consequences, could be beneficial. Encouraging a training environment that fosters positive feedback, sets process-oriented goals, establishes objectives of moderate difficulty, promotes social relationships, and supports body acceptance and self-esteem could be advantageous for professionals involved with Fit Kid.

Our findings underscore the importance of having a team of specialists, such as sports psychologists and nutritionists, to monitor athletes' health, performance, and emotional well-being, taking into account their level of competition and age.

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ADAPTATION OF TESTING PROCEDURES AND STABILIZATION OF RESULTS IN PRESCHOOL RHYTHMIC GYMNASTS

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Abstract

The aim of this study was to familiarize preschool rhythmic gymnasts with testing procedures and to determine the number of familiarization attempts needed to stabilize the test results. Thirty-six female rhythmic gymnasts aged 5.14±0.79 years (body height: 119.44±5.98 cm; body mass: 21.46±3.35 kg) volunteered for the study. All gymnasts were free of injury, trained regularly (two days per week, approximately 60 minutes per session), and participated in the individual B level competitions. The main findings indicated a statistically significant difference between the variables of spine and leg flexibility (p<0.00), standing long jump (p<0.00), balance (p<0.00), and shoulder flexion and extension (p<0.00). According to the results obtained in this research, familiarization can significantly improve scores in motor tests for all variables (spine and leg flexibility, balance, standing long jump, and shoulder flexion and extension) in preschool rhythmic gymnasts. These findings suggest several possibilities for further research, such as investigating the long-term effects of familiarization on motor skill development, the specific mechanisms through which familiarization enhances performance, and its impact across different age groups and skill levels in rhythmic gymnastics. Rhythmic gymnastics trainers and other coaches of aesthetic sports should adapt and introduce participants to test protocols to avoid errors in testing.

Keywords: *flexibility; balance; explosive power; children; movement development.*

INTRODUCTION

Rhythmic gymnastics (RG) is a technical-composite sport that includes elements of gymnastics, dance, ballet, and apparatus manipulation (rope, ball, clubs, and ribbon) (Despina et al., 2014; Douda, Toubekis, Avloniti, & Tokmakidis, 2008; Gateva, 2013; Laffranchi, 2005; Vernetta, Montosa, Beas-Jiménez, & López-Bedoya, 2017). It is associated with elegance, beauty, and excellence in body movement, often set to musical accompaniment (Batista Santos, Lemos, Lebre, & Ávila Carvalho, 2015). These characteristics distinguish RG from other branches of gymnastics. RG requires many hours of training, as selection begins at an early age, and success is only possible through continuous improvement of all the elements involved in the sport (Bobo-Arce & Méndez Rial, 2013; Rutkauskaitė & Skarbalius, 2012). A high level of development in motor skills, rhythm, coordination, agility, and endurance is necessary, with particular emphasis on the collaboration between balance, strength, and flexibility, which play key roles in RG (Batista Santos et al., 2015; Dobrijević, Moskovljević, & Dabović, 2016; Donti, Tsolakis, & Bogdanis, 2014; Laffranchi, 2005). Testing motor skills and monitoring their development is complex, especially when testing children's abilities. It requires a high level of precision, reliability, and objectivity (Tomac, Hraski, & Sporis, 2012). In artistic gymnastics, each gymnastics school has specific models for talent identification (Mkaouer, Hammoudi-Nassib, Amara, & Chaabène, 2018). However, there are limitations in the testing procedures used in rhythmic gymnastics. In many test batteries (Jastrjembskaia & Titov, 1999), the models for testing are specific to mature gymnasts, which preschool children are not familiar with. Determining the profile of a child gymnast and her level of fundamental motor skills could assist coaches in talent identification, as well as in her overall development through training (Šalaj, Milčić, & Šimunović, 2019).

The development of all motor skills mentioned earlier during early childhood provides the foundation for sports skills, as this is when children typically choose the sport whose training they will continue (Busquets, Aranda-Garcia, Ferrer-Uris, Marina, & Angulo-Barroso, 2018). Testing preschool children is necessary to track progress and identify talent for future high-level sports performance (di Cagno et al., 2014). One of the main components of coordinative abilities is balance, which is influenced by a complex interaction of factors, including sensory information (from the somatosensory, visual, and vestibular systems), joint range of motion (ROM), and strength (Ricotti, 2011). Balance is crucial for the correct execution of complex RG movements. Motor skills during early childhood are in a very intensive stage of development, and learning influence is critical (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Fisher et al., 2005). Specific motor skills can be improved with a sufficient level of movement repetition (Pediatrics, 1992). Therefore, it is important to assess the impact of familiarization through testing protocols, especially considering the uncertainties at the preschool age.

Studies on children's development and the improvement of motor skills aim to investigate learning new movement structures and skill proficiency. During the process of motor skill development, children rely on feedback from adults (Sullivan, Kantak, & Burtner, 2008). Some previous studies analyzing the influence of familiarization on sprint running test results have shown varied conclusions. Glaister et al. (2010), for example, demonstrated a positive impact of familiarization on multiple running speed test results, while others found that familiarization did not improve jumping and running test results (Moir, Button, Glaister, & Stone, 2004; Moir, Sanders, Button, & Glaister, 2005). Thomas & Nelson (1996) suggest that individual differences in familiarization with tests and performance situations may explain errors in measurement. Sullivan et al. (2008) studied the effect of different feedback frequencies during practice on the acquisition and retention of motor skills in children compared to adults. Preschoolers significantly improved their results (Međedović et al., 2018) in assessments of leg power, abdominal repetitive strength, running speed, and agility by the final measurement. It appears that feedback and proper instruction enhance children's ability to understand the mechanics of movement in these motor skills (Tomac et al., 2012).

Vrbik et al. (2017) showed significant improvements in polygon backwards and polygon with turn performances, while the vertical jump test, standing long jump, and toe touch test showed no significant improvement during familiarization sessions. The results from Tomac et al. (2012) indicate that, under the influence of familiarization and motor knowledge acquisition, children significantly improved their scores in motor tests of strength and balance.

To the best of our knowledge, research on familiarization with testing procedures in preschool rhythmic gymnasts is limited. Therefore, the aim of this study was to familiarize preschool rhythmic gymnasts with testing procedures and to determine the number of familiarization attempts needed to stabilize the test results.

METHODS

Thirty-six female rhythmic gymnasts aged 5.14±0.79 years (body height: 119.44±5.98 cm; body mass: 21.46±3.35 kg) volunteered for the study. All gymnasts were free of injury, trained regularly (two days per week, approximately 60 minutes per session), and participated at the individual B level. The gymnasts competed 5–6 times per year in national competitions, tournaments, and international cups, as scheduled in the national calendar. Parental consent and child assent were obtained. All tests were performed at the gymnastics club during regular session times. The study was approved by the Ethical Committee of the Faculty of Sport and Physical Education, University of Niš, in accordance with the revised Declaration of Helsinki.

Body mass was measured using an OMRON – BF511 (Omron, Japan), and body height was measured using a GPM Anthropometer (Siber Hegner, Zürich, Switzerland).

Test of *Spine and leg flexibility* is used to determine the degree of flexibility in the spine while bending forward. The gymnast stands on a gym bench, with her toes at the edge of the bench. Her legs should be straight (fully extended), and one hand should be placed on top of the other (overlapped). The tester then instructs the gymnast to lower her hands and slowly reach as far forward as possible. She should reach her maximum stretch and hold that position for two full seconds. A partner should ensure that the gymnast’s legs remain straight throughout the test by lightly holding back the knees. A bench and ruler were used for measurement. Each gymnast is allowed a warm-up trial and two test trials, with the best result being recorded. The tester must ensure the gymnast's toes are aligned with the edge of the bench and that her knees remain straight. The tester measures the distance between the tip of the gymnast’s third finger and the upper edge of the bench. Note: a partner is needed for this test (Jastrjembskaia & Titov, 1999). The gymnast repeats the test four times, and each attempt is measured.

Balance: Static balance was assessed using a sport-specific test for rhythmic gymnastics. The gymnast's goal was to remain on tiptoe ("releve") with arms held above the head (third position) and the free foot in a low passé (fondue) position for as long as possible. Four trials were allowed and recorded using a digital stopwatch (Kioumourtzoglou, Derri, Mertzanidou, & Tzetzis, 1997).

Standing long jump: The gymnast's standing reach height was measured with arms and hands fully extended overhead. The length of the jump was measured to the body part closest to the take-off line (including any fall or step backward) (Dias, Aleksandrova, Lebre, Bobo, & Fink, 2021). The gymnast repeated the test four times, with each attempt being measured.

Shoulder flexion and extension: This test was used to determine shoulder flexibility. The gymnast stood in a straddle position, holding a stick forward with both hands. The gymnast raised the stick upward and then brought it over her back without bending her elbows, keeping the arms fully stretched at all times. A meter stick with centimeter calibrations was used to measure performance (Jastrjembskaia & Titov, 1999). The gymnast repeated the test four times, and each attempt was measured. A reduction in the distance between the hands indicates improved shoulder flexibility. As the gymnast becomes more flexible, she is able to bring her hands closer together behind her back, demonstrating a greater range of motion in the shoulder joint. This metric directly measures shoulder flexibility and assesses the effectiveness of flexibility training exercises.

Physical fitness and body measurements were performed during an evening training session at around 6 p.m. in a bright, warm (19°C) hall. The technical execution of fitness tests was assessed by the same experienced International Gymnastics Federation (F.I.G.) judges and experienced coaches. During the training session, body measurements were taken first, followed by the assessment of physical fitness elements in the following order: balance, upper body flexibility, lower body flexibility, and explosive power. Twenty-four hours before the training session, the gymnasts were asked to avoid any strenuous activity. A standardized rhythmic gymnastics warm-up (including 3 minutes of jogging interspersed with general and specific movements of moderate intensity, 3 minutes of dynamic sport-specific stretching, and 20 minutes of specific warm-up exercises for rhythmic gymnastics) was performed prior to measuring.

Statistical analysis: Data are reported as means and standard deviations (SD). The normality of the distribution was estimated using the Kolmogorov-Smirnov test. For normally distributed results, ANOVA repeated measures were used to determine differences between repeats, while the Independent-Samples Kruskal-Wallis Test was used for non-normally distributed results. Bonferroni post-hoc analysis was also applied. Statistical significance was accepted at $p<0.05$. All analyses were performed using SPSS (version 20.0, SPSS Inc., Chicago, IL, USA).

Table 1

Descriptive parameters and repeated measures analysis

Variable (n=36)	**mean±SD**	**ANOVA repeated measures Kruskal-Wallis Test**
Spine and leg flexibility (cm)		**p-value**
Measurement 1	4.86±5.53	0.00
Measurement 2	7.79±6.12	
Measurement 3	7.72±6.16	
Measurement 4	9.02±6.02	
Balance (sec)		
Measurement 1	1.99±1.07	0.00
Measurement 2	2.33±1.52	
Measurement 3	3.31±2.41	
Measurement 4	3.93±1.98	
Standing long jump (cm)		
Measurement 1	98.55±14.72	0.00
Measurement 2	102.52±16.30	
Measurement 3	105.50±14.20	
Measurement 4	108.77±15.62	
Shoulder flexion and extension (cm)		
Measurement 1	58.13±8.33	0.00
Measurement 2	52.61±7.65	
Measurement 3	49.41±7.82	
Measurement 4	46.91±10.09	

Legend: p-value<0.05 statistical significance; **n-** number of participants.

RESULTS

The descriptive parameters were calculated for each variable (Table 1). ANOVA for repeated measures showed statistically significant differences in two variables: spine and leg flexibility (p<0.00) and standing long jump (p<0.00). The Kruskal-Wallis Test also revealed statistically significant differences in two variables: balance (p<0.00) and shoulder flexion and extension (p<0.00).

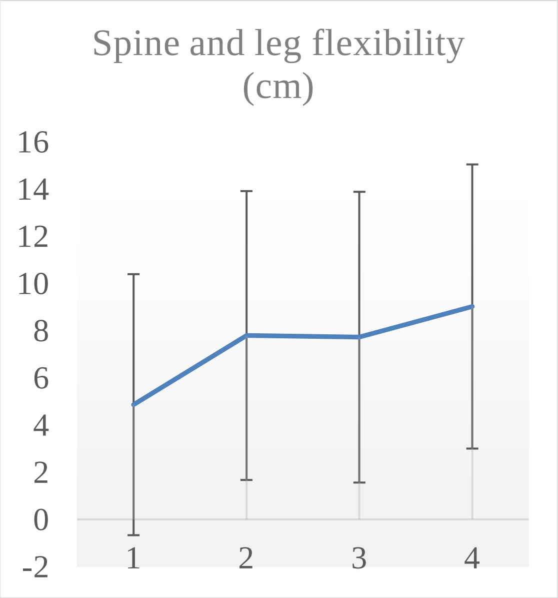

Figure 1. Results of spine and leg flexibility

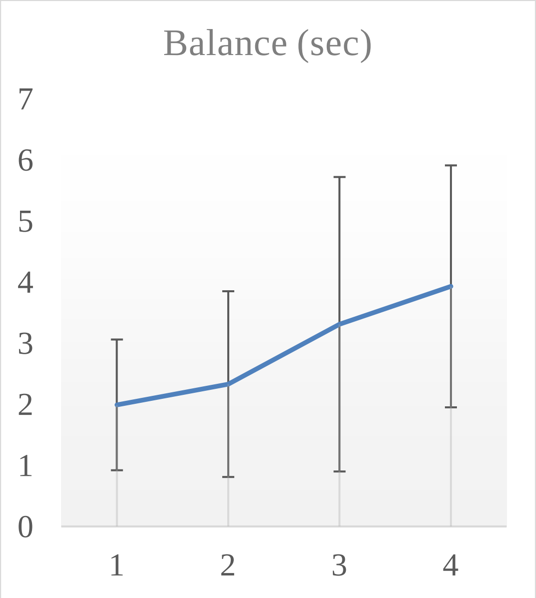

Figure 2. Results of balance

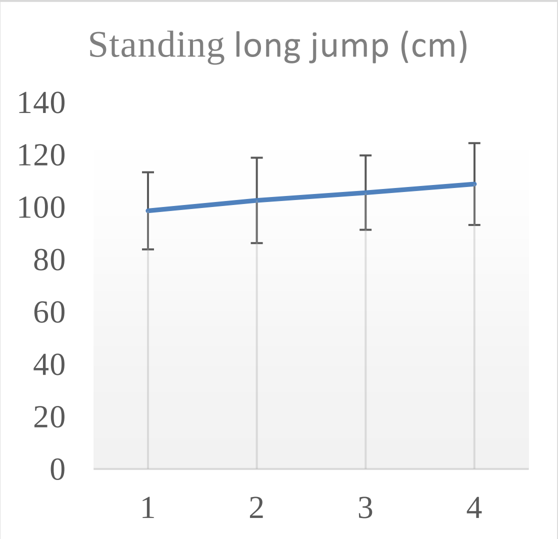

Figure 3. Results of standing long jump

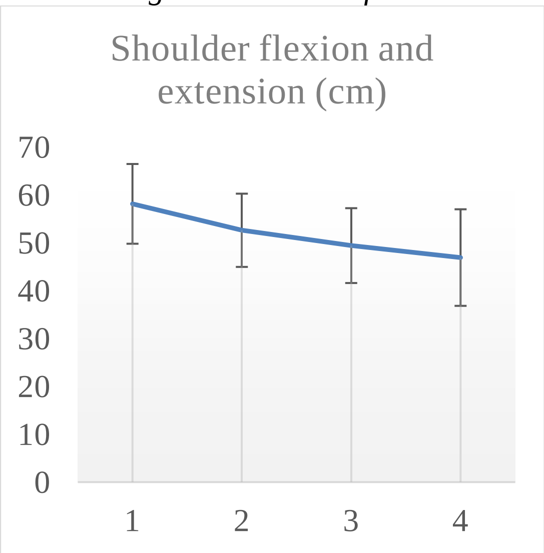

Figure 4. Results of shoulder flexion and extension

Spine and leg flexibility results (Figure 1) showed statistically significant differences between measurements 1 and 2 (p<0.00), 1 and 3 (p<0.00), 1 and 4 (p<0.00), and 3 and 4 (p<0.00). However, there were no statistically significant differences between measurements 2 and 3 (p<1.00), 2 and 4 (p<0.75), or 3 and 4 (p<0.76).

Balance results (Figure 2) showed statistically significant differences between measurements 1 and 3 (p<0.01), 1 and 4 (p<0.00), and 2 and 4 (p<0.00). No statistically significant differences were found between measurements 1 and 2 (p<1.00), 2 and 3 (p<0.23), or 3 and 4 (p<0.36).

Standing long jump results (Figure 3) showed statistically significant differences between measurements 1 and 3 (p<0.00), 1 and 4 (p<0.00), 2 and 4 (p<0.00), and 4 and 3 (p<0.00). However, there were no statistically significant differences between measurements 1 and 2 (p<0.13) or 2 and 3 (p<0.16).

Shoulder flexion and extension results (Figure 4) showed statistically significant differences between measurements 1 and 4 (p<0.00) and 1 and 3 (p<0.00). There were no statistically significant differences between measurements 1 and 2 (p<0.12), 2 and 3 (p<0.49), 3 and 4 (p<1.00), or 4 and 2 (p<0.06).

DISCUSSION

The aim of this study was to familiarize preschool rhythmic gymnasts with testing procedures and to determine the number of familiarization attempts required to stabilize the test results. The main findings indicated statistically significant differences between variables of spine and leg flexibility (p<0.00), standing long jump (p<0.00), balance (p<0.00), and shoulder flexion and extension (p<0.00). These results have several implications for the testing protocol and methodological approach in preschool rhythmic gymnasts, which will be discussed below.

It is recommended to focus on developing flexibility in female gymnasts aged 4-5 years during the elementary phase of training (Pechenevskaya, Kartashova, & Korichko YuV, 2015). The effectiveness of flexibility development techniques has been tested in educational experiments and proven to be effective. Based on our familiarization results (Figure 1), the test should be performed in two trials, as results stabilized in the second trial. Previous research (Vrbik et al., 2017), which investigated familiarization with this testing protocol, found that it could be performed without requiring familiarization trials. The difference in results may be attributed to the older age of the children (10.8 years) in Vrbik et al. (2017) study. The authors explained that the simplicity of the task and the older age of the children were favorable for developing new capabilities, which affected the number of testing attempts, recognition, and stability of the results.

Training younger categories regularly includes positions with both feet on tiptoe as an essential element of all movements in rhythmic gymnastics, as they are often the starting position (Dobrijević et al., 2016). Our study showed that the testing results for balance (Graph 2) were stabilized in the third trial. Research supports the effect of familiarization (Tomac & Hraski, 2016; Tomac et al., 2012; Vrbik et al., 2017) or improvement in balance results after repeated measurements (Dobrijević et al., 2016; Shigaki et al., 2013). Most authors attribute better results to improved coordination of movements and the response of the neuromuscular system (Dobrijević et al., 2016; Vrbik et al., 2017), as well as the activation of larger muscle groups such as the hip-trunk muscles (gluteus, hamstrings, and lower back) (Shigaki et al., 2013).

According to research (Douda et al., 2008), explosive strength is an important determinant of successful performance in rhythmic gymnastics (9.2%). Our study results showed familiarization with the testing protocol for the standing long jump and indicated that results stabilized after four trials (Graph 3). Other studies have reported different results and showed no familiarization effect with this test (Tomac & Hraski, 2016; Tomac et al., 2012; Vrbik et al., 2017). The divergence may be attributed to differences in participant age (Vrbik et al., 2017), as their study included older participants (10.8 years) compared to the current study's participants (5.9 years) (Tomac et al., 2012). Additionally, age groups of 6-7 year old rhythmic gymnasts have shown the lowest annual progress rates in explosive power, estimated at only 2-3% (Zagrevskiy & Beznosikova, 2017), which could be due to insufficiently developed strength at that age.

There is a recommendation for further research on flexibility tests, as well as for considering the use of this fitness component in schools and preschools (Pate, Oria, & Pillsbury, 2012). Shoulder flexibility significantly reduces the risk of injuries in gymnasts (Ling, Sleeper, & Casey, 2020); therefore, the shoulder girdle should be strengthened and tested regularly. Our research on shoulder flexion and extension indicates that familiarization had the most stable results in the third attempt. According to research (Çelik, 2017), shoulder flexibility increased with both cyclic and static stretching after the intervention, and internal rotation strength also improved with cyclic stretching.

The significant differences observed in spine and leg flexibility suggest that flexibility training should be tailored to the individual needs of preschool gymnasts. Familiarization with the testing protocol indicates that stability in flexibility results can be achieved with two trials, underscoring the importance of repetitive practice in enhancing flexibility at an early age. The results regarding balance tests, which stabilized after three trials, highlight the necessity of incorporating regular balance training into preschool gymnastics programs. This is consistent with existing literature that emphasizes the role of neuromuscular coordination and muscle group activation in improving balance (Dobrijević et al., 2016; Shigaki et al., 2013). Regular balance exercises can help young gymnasts achieve the stability required for more complex movements in rhythmic gymnastics.

The familiarization with the standing long jump test and the need for four trials to achieve stable results imply that explosive strength training should be gradually introduced and regularly practiced. The divergence from other studies, which found no need for familiarization, suggests that the age and developmental stage of the gymnasts are critical factors. Younger gymnasts may require more frequent practice to develop the explosive strength needed for successful performance in rhythmic gymnastics.

The stabilization of shoulder flexion and extension results after three attempts indicates the importance of regular flexibility and strength training for the shoulder girdle. This aligns with research suggesting that shoulder flexibility reduces injury risk (Ling, Sleeper, & Casey, 2020). Implementing regular shoulder flexibility assessments and targeted training can help prevent injuries and enhance overall performance.

The implications of this study extend to educational programs and policy recommendations for preschool physical education. The evidence supporting the importance of flexibility, balance, and explosive strength training in young children underscores the need for incorporating these components into school and preschool curricula (Pate, Oria, & Pillsbury, 2012). This can contribute to the overall physical development and well-being of children, promoting lifelong fitness habits.

The limitations of this study include the sample selection, specifically the insufficient number of respondents and the lack of more specific tests for rhythmic gymnastics and the assessment of motor skills in preschoolers. With the help of these specific tests, we could more accurately determine the impact of familiarization on other motor skills, which would aid in the development of future testing protocols.

Further studies should be longitudinal to determine whether the training process affects the familiarization of movements and testing protocols.

CONCLUSION

According to the results obtained in this research, familiarization can significantly improve scores in motor tests across all variables (spine and leg flexibility, balance, standing long jump, and shoulder flexion and extension) for preschool rhythmic gymnasts. These findings suggest several possibilities for further research, such as investigating the long-term effects of familiarization on motor skill development, the specific mechanisms through which familiarization enhances performance, and its impact across different age groups and skill levels in rhythmic gymnastics. An important factor in improving performance quality is understanding the task. Rhythmic gymnastics trainers and other coaches of aesthetic sports should adapt and introduce participants to test protocols to avoid errors in testing. Feedback information and adequate instructions increase gymnasts' ability to better understand the mechanics of movement in the mentioned motor skills. As in previous research, this study confirmed that the process of familiarization with testing procedures and the feedback provided is an important factor in the motor evaluation of preschool rhythmic gymnasts.

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ANALYSIS OF THE SPINAL CURVATURE IN RHYTHMIC GYMNASTICS ATHLETES OF DIFFERENT COMPETITIVE LEVELS AND WITH DIFFERENT POSTURES

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Abstract

Rhythmic gymnastics is characterized by high mobility demands on the spine, which can lead to structural changes and associated injuries or pain. The aim of this study is to assess and compare spinal posture in different positions, mobility, and pain perception among RG athletes. The sample consisted of 34 gymnasts (age: 14.18 ± 2.17) of grassroots and federation levels. Spinal posture and mobility were analyzed using the Spinal Mouse® system, along with pain perception (location and intensity) and body composition. Most gymnasts exhibited normal spinal curvature in both standing and sitting positions. Significant differences ($p<0.05$) were only found in the sacral curve during extension. Regarding lumbar mobility, differences in sacral mobility from standing to extension were noted, with the federation-level gymnasts showing a greater tendency for hyperlordosis in extension. In terms of pain, the lumbar region was the most affected, with 32.4% of cases reporting pain. It was observed that gymnasts experiencing pain displayed more pronounced lumbar hyperlordosis in the standing position. A low but significant correlation was found between lumbar pain and its intensity ($p=0.045$), and a moderate correlation was observed between hip pain and pelvic tilt. The gymnasts demonstrated a greater tendency for lumbar hyperlordosis in the standing position and during the transition from standing to extension, which was more pronounced among federation-level gymnasts. Furthermore, there appears to be a stronger correlation between hyperlordosis and the occurrence of lumbar pain, as well as the intensity of pain.

Keywords: *Spinal Mouse®, anthropometry, spinal curvature, pain, rhythmic gymnastics.*

INTRODUCTION

Analyzing the components of training load, particularly the volume of repetitive work in specific postures unique to the sport, can lead to musculoskeletal and spinal deterioration (López-Miñarro et al., 2011; Mahdavie et al., 2017; Muyor et al., 2011; Sainz de Baranda et al., 2010; Zemková et al., 2020). The analysis of the spine and its integrity has been addressed by various disciplines, including the study of dorsal and lumbar sagittal curves. Assessing spinal curvature is important due to its influence on the mechanical properties of intervertebral tissues under load, which increases forces and the potential for injury in young athletes (López-Miñarro et al., 2011; Muyor et al., 2011; Smith et al., 2008; Steinberg et al., 2021). Keller et al. (2005) studied the impact of the angular arrangement of lumbar and thoracic curves on the shearing and compression of intervertebral structures.

It is therefore essential to examine the correlation between repetitive sport practice and spinal alignment to understand its effect on spinal morphotype. Rhythmic gymnastics (RG) is among the sports that involve repeated actions of vertebral flexion, bending, and rotation, with forced movements at maximum intensity and improper loading postures (Maroon & Bailes, 1996). To assess RG's impact on spinal alignment, it is necessary to identify common modifications in the sagittal plane and determine whether they contribute to pathologies or improve spinal curvature (Vaquero et al., 2015).

Some studies have found that ballet dancers suffer from spinal hypermobility, hyperlaxity, or generalized hypermobility, which is associated with lumbar pain (Armstrong, 2018a, 2018b; Bukva et al., 2019; Sands et al., 2016; Steinberg et al., 2021). Additionally, it has been observed that dance training is associated with increased lumbar kyphosis during maximum trunk flexion with the knees extended (Esparza-Ros et al., 2014). In RG, studies have analyzed the posture and common spinal alterations among gymnasts, with lumbar hyperlordosis being the most characteristic postural change in the sagittal plane (Ambegaonkar et al., 2014; Bosso & Golias, 2012).

Differences in competitive levels result in varying physical demands and training loads, which can lead to different physiological responses. Conversely, other authors have highlighted the postural benefits of RG, emphasizing postural education, strength, endurance, and flexibility in the lumbar and hamstring regions, all of which are crucial for proper spinal alignment (Conesa Ros & Martínez-Gallego, 2017; Jaime-Gil et al., 2021; Martínez-Gallego, 2004; Piazza et al., 2009; Sands et al., 2016).

The aim of this study is to assess and compare the postural alignment of the spine in standing, sitting, maximum flexion, and maximum extension positions, as well as to evaluate mobility and the perception of musculoskeletal pain, in grassroots- and federation-level rhythmic gymnasts. aim of this study is to assess and compare the postural alignment of the spine in standing, sitting, maximum flexion, and maximum extension positions, as well as to evaluate mobility and the perception of musculoskeletal pain, in grassroots- and federation-level rhythmic gymnasts.

METHODS

The sample consisted of 34 grassroots- and federation-level rhythmic gymnastics (RG) athletes, aged 12 to 18 years. The mean age ($\bar{X}$) was 14.18 ± 2.17 years. The grassroots-level group included 20 gymnasts (mean age: 13.75 ± 2.24), while the federation-level group included 14 gymnasts (mean age: 14.79 ± 1.97). The grassroots and federation categories have different requirements: the grassroots level involves a lower degree of difficulty, with a scoring code adapted to national regulations, whereas the federation level applies the highest degree of difficulty, following the International Gymnastics Federation scoring code.

The inclusion criteria were: being female, having at least 3 years of experience in rhythmic gymnastics, and participating in grassroots or federation competitions. The exclusion criteria were: having a current pathology or muscle/joint injuries (within the past 6 months), having a spinal pathology, or having undergone surgery on the spine or hamstring muscles.

All participants were informed about the study procedures and provided signed informed consent. The research complies with the principles of the Declaration of Helsinki and relevant local and national legislation. The gymnasts are members of two of the largest clubs in the province of Pontevedra (Spain).

Height, weight, fat-free mass, fat mass, body fat percentage, and fat-free percentage were measured. Waist and hip circumferences were also recorded, from which the waist-hip ratio [waist (cm)/hip (cm)] was calculated. Another proportionality index determined was the Body Mass Index (BMI) [weight/height^2 (kg/m^2)].

Postural assessment was based on the angular alignment of spinal curves and pelvic tilt. The Spinal Mouse® system (Idiag, Fehraltdorf, Switzerland) was used, applied from the seventh cervical vertebra (C7) to the third sacral vertebra (S3), both of which were previously located and marked. The variables measured included the joint angles between the sacrum and hip bone, thoracic curve, lumbar curve, and pelvic tilt in each position (standing, flexion, extension, and sitting). Additionally, the mobility of the thoracic, lumbar, and sacral regions, as well as tilt changes between standing-flexion, standing-extension, and flexion-extension positions, were analyzed.

The Spinal Mouse® system has been validated and proven reliable for assessing spinal curves and pelvic tilt (Demir, 2020; Guermazi et al., 2006; Mannion et al., 2004; Post & Leferink, 2004; Zanguie et al., 2023). Standing measurements were conducted according to the protocol developed by Muyor et al. (2011), while the other postures followed techniques described by Martínez-Gallego (2004), Vaquero et al. (2015), and García Vélez (2019). Normal values for relaxed standing were based on those defined by López-Miñarro et al. (2007), for asthenic sitting and maximum trunk flexion on those defined by Martínez-Gallego (2004), and for maximum spinal extension in the standing position on the parameters preset in the Spinal Mouse software.

To assess pain perception, a numerical scale from 0 to 10 was used to identify the body areas where gymnasts regularly experience pain, with 0 corresponding to no pain/interference and 10 representing the worst imaginable pain/interference. Scores from 0 to 3 indicated light pain, 4 to 7 moderate pain, and 8 to 10 severe pain. The body regions analyzed were grouped into the hip, lumbar, and dorsal areas.

A descriptive and comparative analysis of the studied variables was conducted, using the mean ($\bar{X}$) as a measure of central tendency and the standard deviation (SD) as a measure of data dispersion for numerical variables, while frequencies and percentages (%) were used for categorical variables. A comparative analysis between groups was also performed. To test the normality of the data, the Shapiro-Wilk test was applied, and homogeneity of variance was assessed using Levene's test. The Student's t-test was used to compare numerical variables between two groups or categories, while the Mann-Whitney U test was employed for variables with a non-normal distribution. Additionally, the Student's t-test for related samples was used to compare spinal curves in the standing and sitting positions, with the Wilcoxon test used for non-normal variables.

Spearman's correlation coefficient was employed to analyze the correlation between pain intensity and various postural and mobility variables. Data were analyzed using SPSS 22.0 statistical software, with a significance level of $p<0.05$ for all tests.

RESULTS

The values obtained for anthropometric variables, years of training, and weekly training hours showed no significant differences between the grassroots and federation levels, allowing us to conclude that both groups were homogeneous (Table 1).

The categorization of the spinal curves in standing and seated position is mostly normal (Figure 1 and 2).

Table 1

Descriptive study of anthropometric variables, years of sport practice, weekly training hours and comparison between grassroots- and federation-level gymnasts.

	Total (n=34)		Grassroots-level (n=20)		Federation-level (n=14)		
	X	SD	X	SD	X	SD	Sig. (bilateral)
Height	1.5537	.09085	1.5396	.09314	1.5739	.08677	.290†
Weight	48.3824	10.58236	47.5900	11.07068	49.5143	10.13910	.609
BMI	19.8076	2.63141	19.8293	2.83465	19.7767	2.41488	.955
Waist circumference (cm)	61.7118	5.34358	61.0700	5.20891	62.6286	5.59360	.411
Hip circumference (cm)	84.9618	9.52305	84.5650	10.08993	85.5286	8.99037	.776
WHR	.7295	.04440	.7259	.04548	.7346	.04397	.583
% body fat	16.9735	8.85600	16.6400	9.43863	17.4500	8.27450	.904†
% fat free	83.0265	8.85600	83.3600	9.43863	82.5500	8.27450	.904†
Years of training	8.62	2.257	8.25	1.773	9.14	2.797	.304
Training hours per week	13.79	3.109	13.65	3.628	14.00	2.287	.931†

[Mean (X); Standar Deviation (SD); Body Mass Index (BMI); Waist-hip ratio (WHR)] †U de Mann-Whitney *p<0.05

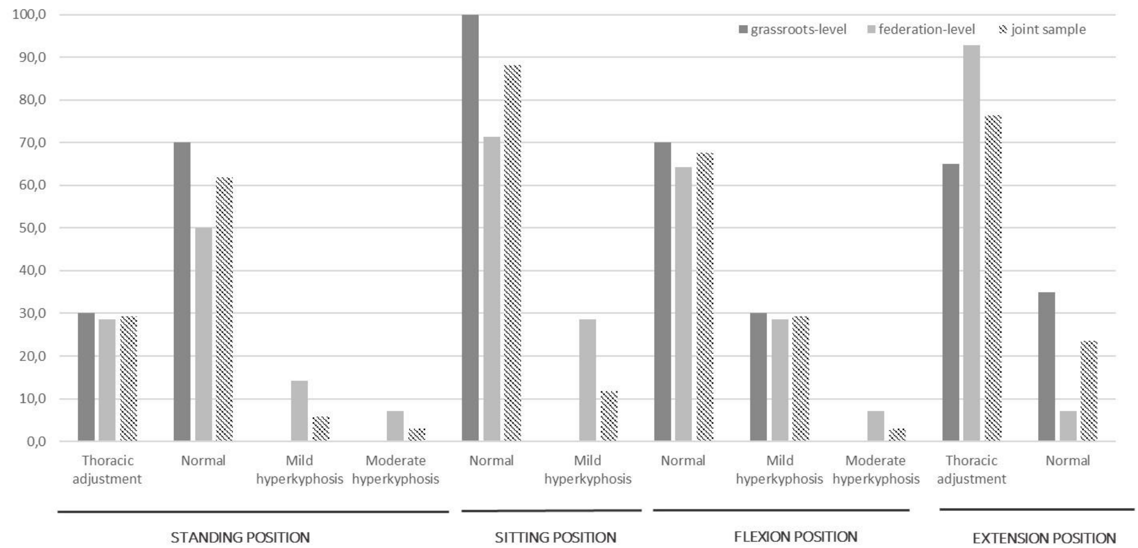

Figure 1. Categorization of thoracic spine curves

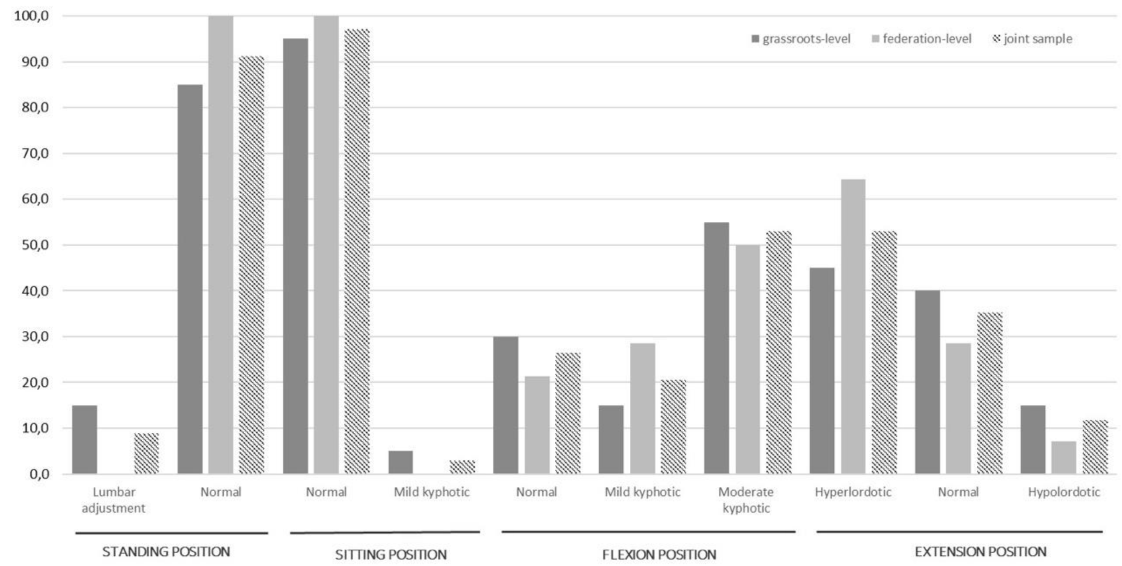

Figure 2. Categorization of the curves of the lumbar spine

Table 2
The sacral, thoracic, and lumbar spinal curves and pelvic tilt in each position and comparative analysis between the grassroots-level and federation-level groups.

	Total (n=34)		Grassroots-level (n=20)		Federation-level (n=14)		
	X	SD	X	SD	X	SD	Sig. (bilateral)
Sacrum hip in standing position	19.50º	6.316	19.90º	7.476	18.93º	4.358	.637
Sacrum hip in flexion position	105.15º	14.722	106.15º	15.882	103.71º	13.333	.642
Sacro hip in extension position	21.91º	97.839	19.45º	105.334	25.43º	89.780	.030†*
Sacro hip in sitting position	14.59º	7.488	13.05º	7.681	16.79º	6.874	.155
Thoracic curve in standing position	20.88º	26.369	17.35º	26.615	25.93º	26.137	.500†
Thoracic curve in flexion position	45.26º	10.632	44.50º	10.435	46.36º	11.209	.691†
Thoracic curve in extension position	-.09º	24.667	6.75º	25.786	-9.86º	19.949	.052
Thoracic curve in sitting position	18.74º	19.300	17.65º	14.957	20.29º	24.783	.457†
Lumbar curve in standing position	-28.56º	6.268	-28.80º	7.302	-28.21º	4.644	.793
Lumbar curve in flexion position	28.62º	10.566	28.95º	11.941	28.14º	8.637	.830
Lumbar curve in extension position	-65.76º	18.159	-62.50º	19.435	-70.43º	15.658	.215
Lumbar curve in sitting position	-8.29º	12.717	-5.85º	14.199	-11.79º	9.673	.184
Pelvic tilt in standing position	3.32º	4.117	3.35º	4.804	3.29º	3.049	.743†
Pelvic tilt in flexion position	136.82º	12.677	138.30º	12.482	134.71º	13.117	.425
Pelvic tilt in extension position	-63.47º	10.880	-65.15º	11.824	-61,07º	9.253	.289
Pelvic tilt in sitting position	12.44º	5.971	11.85º	5.842	13.29º	6.269	.499

[Mean (X); Standar Deviation (SD)] †U de Mann-Whitney *p<0.05

Table 2 shows the degrees of spinal curvature in the different positions (standing, sitting, flexion, and extension). In the comparative analysis between grassroots-level and federation-level gymnasts, significant differences (p<0.05) were observed only in the curvature formed by the sacrum and hip bones during extension. Federation-level gymnasts displayed a greater curvature, indicating a higher tendency for hyperlordosis (Table 2).

In the comparative analysis, significant differences (p<0.001) were found in the spinal curvatures between the standing and sitting postures. There was a greater tendency for hyperlordosis in the sacral curve (p=0.003) and an increased lumbar curvature (p=0.000) in the standing position, along with a greater pelvic tilt (p=0.000) in the sitting position. Similar differences were observed among grassroots-level gymnasts, with significant variations in the sacral (p=0.005) and lumbar curves (p=0.000), and in pelvic tilt (p=0.000). Federation-level gymnasts showed significant differences only in the lumbar curve (p=0.000) and pelvic tilt (p=0.000), with more pronounced lordosis in the standing posture.

Table 3 presents the mobility analysis of different spinal regions. The comparative study between gymnast levels revealed significant differences (p<0.05) in the sacral region concerning mobility from standing to extension. Federation-level gymnasts showed an increased degree of curvature in the extension posture compared to standing, indicating a greater tendency for hyperlordosis in extension. Conversely, grassroots-level gymnasts exhibited a decrease in curvature, suggesting a lesser tendency for hyperlordosis in extension compared to the standing posture.

Significant differences (p<0.05) were also found in the extension-to-flexion motion for the sacrum and the thoracic curve. The sacral region showed a greater increase in curvature for grassroots-level gymnasts compared to federation-level gymnasts, indicating a higher tendency for hyperlordosis in flexion among grassroots-level gymnasts. In the thoracic region, federation-level gymnasts demonstrated a higher degree of curvature than grassroots-level gymnasts, reflecting a greater tendency for kyphosis in flexion among federation-level gymnasts.

35.3% of gymnasts experience some degree of pain, with 40% of grassroots-level gymnasts and 28.6% of federation-level gymnasts reporting pain. The most common pain location across the pooled sample was the lumbar region, followed by the hip, and then the dorsal region. In federation-level gymnasts, although the lumbar region remained the most common area of pain, the second most common location was the dorsal region, with no cases of hip pain.

When analyzing hip pain separately, it was found that 14.7% of the total participants experienced this type of pain, including 25% of grassroots-level gymnasts. Dorsal pain was reported by 5.9% of participants, with 5% of grassroots-level and 7.1% of federation-level gymnasts affected. The highest incidence of pain was observed in the lumbar region, affecting 32.4% of the cases, including 35% of grassroots-level and 28.6% of federation-level gymnasts.

Table 3 shows the distribution of pain intensity by spinal region for those gymnasts who experienced pain. Lumbar pain was the most common in both groups, with the highest pain scores recorded. The intensity of pain was similar across both competitive levels (Table 3).

To analyze the relationship between experiencing pain and postural patterns, gymnasts were first divided into two groups: those who experienced pain in any region and those who did not. They were then further categorized into two groups based on whether they experienced lumbar pain or not. The analysis revealed significant differences in lumbar curvature in the standing posture, with those who experienced any type of pain showing greater lumbar hyperlordosis (Table 4).

Table 3
Intensity of pain perception in the pooled sample and in the grassroots- and federation-level groups.

	Total				Grassroots-level				Federation-level			
	n	X(SD)	Mín	Máx	n	X(SD)	Mín	Máx	n	X(SD)	Mín	Máx
Perception of hip pain	5	6.8(0.46)	6	7	5	6.80(0.45)	6	7	0			
Perception of thoracic pain	2	6.5(0.71)	6	7	1	7	7	7	1	6	6	6
Perception of lumbar pain	11	7.18(1.25)	5	9	7	7.14(1.57)	5	9	4	7.25(0.50)	7	8

[Mean (X); Standar Deviation (SD)]

Table 4
Comparison of spinal morphology between gymnasts with and without pain, and between gymnasts with and without lumbar pain.

	No pain (n=22)		Pain (n=12)			No lumbar pain (n=23)		Lumbar pain (n=11)		
	X	SD	X	SD	Sig	X	SD	X	SD	Sig
Sacrum hip in standing position	19.27º	6.833	19.92º	5.501	.781	19.26º	6.676	20.00º	5.762	.755
Sacrum hip in flexion position	102.23º	14.155	110.50º	14.811	.119	102.96º	14.265	109.73º	15.278	.215
Sacro hip in extension position	7.86º	74.135	47.67º	130.792	.657†	7.48º	72.454	52.09º	136.231	.800†
Sacro hip in sitting position	13.55º	7.614	16.50º	7.167	.278	13.61º	7.445	16.64º	7.500	.277
Thoracic curve in standing position	18.32º	29.325	25.58º	20.174	.557†	19.09º	28.887	24.64º	20.877	.717†
Thoracic curve in flexion position	48.18º	9.200	39.92º	11.373	.058†	47.96º	9.053	39.64º	11.885	.084†
Thoracic curve in extension position	1.14º	22.710	-2.33º	28.849	.701	2.30º	22.884	-5.09º	28.550	.422
Thoracic curve in sitting position	15.73º	22.224	24.25º	11.104	.204†	16.00º	21.753	24.45º	11.622	.188†
Lumbar curve in standing position	-26.86º	5,955	-31.67º	5,821	**.030***	-27.13º	5.957	-31.55º	6.089	.053
Lumbar curve in flexion position	29.95º	11,408	26.17º	8,737	.325	29.70º	11.215	26.36º	9.135	.398
Lumbar curve in extension position	-66.77º	17,320	-63.92º	20,268	.668	-67.39º	17.180	-62.36º	20.495	.459
Lumbar curve in sitting position	-5.77º	13,402	-12.92º	10,308	.119	-6.13º	13.206	-12.82º	10.806	.154
Pelvic tilt in standing position	4.18º	4,159	1.75º	3,696	.094†	4.04º	4.117	1.82º	3.868	.143†
Pelvic tilt in flexion position	135.50º	12,301	139.25º	13,539	.418	135.96º	12.216	138.64º	14.023	.572
Pelvic tilt in extension position	-62.41º	11,492	-65.42º	9,830	.450	-62.04º	11.364	-66.45º	9.595	.275
Pelvic tilt in sitting position	13.18º	5,885	11.08º	6,142	.335	12.87º	5.941	11.55º	6.219	.553

[Mean (X); Standar Deviation (SD)] † U de Mann-Whitney *p<0.05

When comparing mobility between groups with or without pain, and those with or without lumbar pain, none of the variables showed significant differences between the groups experiencing general or lumbar pain. However, a notable difference, though not significant, was observed in sacral mobility from standing to extension. Gymnasts with pain exhibited a greater tendency for hyperlordosis in extension, while those without pain showed a reduced tendency for hyperlordosis.

To explore the relationship between the intensity of lumbar, thoracic, and hip pain and various spinal curves, inclinations, and mobility, a correlation study was conducted. For lumbar pain, lumbar curvature in the standing position was the only variable with a significant relationship (p=0.045), with a Spearman's Rho coefficient of -0.346, indicating a low correlation. This suggests that greater lumbar lordosis in the standing position is associated with higher pain levels. For hip pain, a significant correlation was found with thoracic curvature in extension (p=0.04), with a correlation coefficient of 0.354, showing a low correlation. Additionally, a significant correlation was observed with pelvic tilt in the standing position (p=0.01), with a Spearman's Rho coefficient of -0.434, indicating a moderate correlation; greater pain was associated with a lesser pelvic tilt. No significant correlation was found between dorsal pain intensity and any of the analyzed variables.

DISCUSSION

The primary objective of this study was to compare normality ranges in various basic and sport-specific postures, and to determine if deviations from normality were more pronounced in forced versus relaxed postures. Additionally, the study aimed to compare mobility ranges and pain perception across different competitive levels (grassroots and federation-level). Research on this topic is limited, but protocols for ballet dancers—a discipline with requirements thought to be comparable to rhythmic gymnastics (RG)—are available (Vaquero et al., 2015).

The first finding was that gymnasts generally displayed normal thoracic values in standing and sitting postures. However, during maximum extension, most gymnasts, particularly those at the federation level, showed a tendency for thoracic adjustment. Ballet dancers also exhibited a tendency for thoracic adjustment, with values of 18.51±10.71º, falling within <20º (Vaquero et al., 2015). In contrast, RG athletes in the standing posture were within normal standards, with a mean of 20.88º, indicating that this posture did not align with the analyzed sample (Vaquero et al., 2015). Notably, grassroots gymnasts had greater thoracic adjustment values (17.35º±26.615º) compared to federation-level gymnasts (25.93º±26.137º). This suggests that competitive level differences influenced this aspect in the opposite direction from what was initially predicted.

In standing posture, ballet dancers had a lumbar curve of -24.74±8.53º, which falls within the intermediate range of -20º to -40º (Vaquero et al., 2015). Gymnasts in our study had a similar mean lumbar curve of -28.56º±6.268, also within the range of -20º to -40º, indicating a tendency towards hyperlordosis in rhythmic gymnastics.

At maximum trunk flexion, the thoracic region showed similar results between our study and that of Vaquero et al. (2015). Ballet dancers had a mean thoracic curve of 42.61±11.14º, while gymnasts had a mean of 45.36±10.632º. This similarity suggests that both disciplines impose similar demands on thoracic curvature in this posture. For the lumbar curve, gymnasts exhibited a pattern of kyphosis at maximum trunk flexion, similar to ballet dancers (Esparza-Ros et al., 2014).

In the sitting posture, ballet dancers had a thoracic curve value of 6.32±9.84º (Vaquero et al., 2015). In contrast, rhythmic gymnasts had a mean of 18.74º±19.30º, reflecting a normal thoracic curve. The lower values in ballet dancers could be attributed to scapular retraction. The postural reeducation associated with these disciplines likely helps avoid the hyperkyphotic tendency typical in the general population. The flexibility of the ischiosural muscles in gymnasts might reduce the kyphotic curve, minimizing the load on the thoracic area. However, our study found that most gymnasts exhibited greater thoracic adjustment without a tendency towards kyphosis in relaxed postures.

It should be noted that mobility from standing to extension was greater in federation-level gymnasts compared to grassroots-level gymnasts. Federation-level gymnasts demonstrated a larger range of movement in the sacral region, which may indicate a tendency towards hyperlordosis in this posture and could be associated with an increase in lumbar pain.

In fact, 34.5% of gymnasts experienced lumbar pain, with federation-level gymnasts exhibiting the highest prevalence in this region. In contrast, grassroots-level gymnasts reported more distributed pain across other sections. These findings are consistent with other research studies (Armstrong, 2018a, 2018b; Bukva et al., 2019; Deighton, 2005; Sands et al., 2016; Steinberg et al., 2021). It is crucial to seek preventive measures to ensure that increased mobility does not negatively impact high-level competitive gymnasts, particularly in the lumbar region.

It is important to acknowledge several limitations of this study. Firstly, the sample size for federation-level gymnasts was smaller compared to that of grassroots-level gymnasts. Although the hours and types of training are relatively similar at both levels, with only minor adjustments to federation standards, differences might be more pronounced if other levels of competition, such as pre-grassroots, were included. These lower-level gymnasts generally have fewer training hours and less demand. Additionally, gymnasts experiencing pain, particularly those with specific organic conditions like spondylolysis or Bertolotti syndrome secondary to sacralisation, were not assessed using imaging methods, which could provide more detailed insights into their conditions.

CONCLUSIONS

Rhythmic gymnasts exhibit specific alterations in spinal curvature, notably a greater tendency towards lumbar hyperlordosis, particularly evident in federation-level gymnasts. There appears to be a stronger correlation between hyperlordosis and the occurrence of lumbar pain, as well as with the intensity of training.

Federation-level gymnasts have a higher prevalence of low back pain. Despite this, rhythmic gymnastics provides postural control benefits in positions such as sitting, leading to a reduced kyphotic tendency in the thoracic region during relaxed standing and asthenic sitting.

These findings underscore the need for further research into sports that involve hypermobility and laxity. Such studies could provide a scientific basis for physical trainers and sports rehabilitators to develop strategies aimed at reducing injury rates. Increasing strength training for the abdominal and lumbar muscles may be particularly beneficial, as it could help alleviate localized or distributed pain.

Declaration of competing interest:
The authors have no relevant financial or non-financial interests to disclose.

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Ethical statement:
The study was approved by the Autonomous Ethics Committee of Research of Xunta de Galicia (Spain) (Reference Number 2023/020).

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RELATIONSHIP BETWEEN SHOULDER FLEXIBILITY AND HANDSTAND ALIGNMENT IN DIFFERENT FEMALE ARTISTIC GYMNASTICS APPARATUS

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Abstract
A study was performed with the objective of analyzing the relationship between shoulder flexibility and handstand performance across three female artistic gymnastics apparatuses: floor exercise (FX), balance beam (BB), and uneven bars (UB). Twenty-one gymnasts participated and were divided into two groups: "G1", consisting of twelve child gymnasts, and "G2", consisting of nine adolescent gymnasts, aged 9 and 14 respectively. The study aimed to consider the sensitive phases for the development of flexibility. Using the Kinovea program, the shoulder angle (°H) in the handstand and the alignment of the joint segments (AJS) involved were analyzed. Participants underwent two different active shoulder flexibility tests (GFMT and FIG), and results were compared between the groups. Significant differences were found between groups in the GFMT test (p = 0.018), the FIG test (p = 0.026), and AJS in the BB handstand (p = 0.043). Significant relationships were also observed between the GFMT test and °H in UB (p = 0.021); and between the FIG test and °H in BB (p = 0.006), both withing the cild gymnast group. Overall, the adolescent group presented better scores, supporting the notion of greater body awareness and technical mastery of the handstand across the different female artistic gymnastics apparatuses.

Keywords: *ROM, shoulder angle, handstand, sport performance.*

INTRODUCTION

In the long-term development of gymnasts, overall loading ability, particularly the loading ability of the motor and support systems, holds a central position (Fink, Hofmann, & Ortiz López, 2021). Poor posture can compromise the athlete's entire system and, due to the systematic strength training undertaken by gymnasts, may exacerbate existing muscle shortenings and create new ones (Bessi, 2016). According to the FIG (2021), achieving safe, systematic development and avoiding inefficient joint positions requires a high level of prerequisites such as flexibility, strength, and basic structural development. Optimal mobility ranges enhance technical efficiency and provide greater possibilities for performance (Weineck, 2005). This increase in mechanical efficiency results from executing sports movements at the limits of motion (Dantas, 2012). A gymnast lacking flexibility will have to exert more effort and will fatigue more quickly (Bessi, 2016). Flexibility limitations can lead to learning errors and faulty movement patterns, resulting in defective movement engrams

(Di Santo, 1997). Therefore, it is essential to thoroughly study the minimum angular amplitudes required for specific movements or gestures for each joint (Di Santo, 1997). The joint must possess both mobility and stability simultaneously—two seemingly opposite qualities (Dantas, 2012).

Gómez-Landero Rodríguez (2013) analyzed the correlations between variables related to active and passive flexibility and sports performance in trampolinists. McLaren et al. (2015) identified the mean angle of the wrist joint during a backward flic-flac in gymnasts and concluded that there is a relationship between the angle of wrist impact and the angle of shoulder flexion. León-Prados et al. (2011) verified the relationship between certain flexibility tests and competitive performance in male gymnasts across different apparatuses.

Many movements in gymnastics require a high degree of joint amplitude (Di Santo, 1997). The handstand often serves as the starting, finishing, or transition position between various elements, making its mastery central to the training and development of gymnasts (Bessi, 2016). The joints, from the wrist to the ankle, must be aligned along the same axis perpendicular to the ground, with scapulo-humeral flexibility being crucial. This flexibility must reach at least 180°; otherwise, the center of gravity of the trunk and lower limbs will be misaligned (Di Santo, 1997). The force of gravity on the respective barycenters of the different body segments is nearly aligned along a straight line (Bessi, 2016). A limitation in shoulder flexibility restricts the "open shoulder angle" position (Uzunov, 2008).

Several studies have highlighted the importance of strategies for maintaining handstand balance and the varied muscular activity involved (Kochanowicz et al., 2018; Rohleder & Vogt, 2019). Rohleder and Vogt (2018a; 2018b) explored the use of various feedback stimuli to improve and maintain posture. Gautier et al. (2007) evaluated the role of central and peripheral vision in the postural regulation of the handstand. Kochanowicz et al. (2017) described differences in muscle activation during handstands on different apparatuses in male gymnasts, considering variations in grips and hand positions. These coordinated responses involve feedback from the proprioceptive, visual, and vestibular systems (Uzunov, 2008).

Irurtia et al. (2010) evaluated flexibility in gymnasts and its evolution in relation to specific training. Other researchers have proposed measurement programs with various tests, including specific tests for assessing active shoulder joint flexibility (Gómez-Landero Rodríguez et al., 2011; Sleeper et al., 2012; Sleeper et al., 2016; Vernetta et al., 2017; Mkaouer et al., 2018). The FIG Age Group Program (Fink et al., 2021), within the "Physical Ability Development and Testing Program," offers a different alternative. Considering the sensitive phases for the development of flexibility, as proposed by Issurin (2012), between the ages of 7 and 10, and specifically by authors specializing in artistic gymnastics who suggest that the training/adaptation relationship between ages 6 and 12 is highly favorable for developing this ability (Bessi, 2016), it would be expected to find differences between child and adolescent gymnasts in joint ranges and postural control in both tests and more complex situations such as gymnastic elements.

The objectives of this study were:

1. To investigate the relationship between the ranges of shoulder joint flexibility in flexion with °H in the handstand and AJS in the handstand across different apparatuses in child and adolescent gymnasts.
2. To compare both groups in terms of shoulder flexibility, °H, and AJS in the handstand on FX, BB, and UB.

METHODS

An observational study was conducted involving 21 female artistic gymnasts from the Molins de Rei Gimnàs Club in

Barcelona. Following the criteria established by Bessi (2016), the gymnasts were divided into two groups: G1, consisting of 12 gymnasts aged 7 to 12 years, and G2, consisting of 9 gymnasts aged 13 to 17 years (Table 1).

The inclusion criteria were:
a) Having more than one year of artistic gymnastics training.
b) Being able to perform a handstand on FX, BB, and UB, with an alignment within 10° of the handstand position, as required by the gymnastics scoring code to be considered valid (FIG, 2020).
c) Training at least three times a week for a minimum of three hours per session.
d) Not having any excluding injuries.

All participants were informed about the study, and written informed consent was obtained from their parents or legal guardians. This study was conducted in accordance with the Declaration of Helsinki and the International Principles governing research, and it received a favorable opinion from the Bioethics Commission of the University of Barcelona.

Table 1
Descriptive profile of Group 1 and Group 2 (Mean ± SD).

	Age	Weight	Height	IMC	Years of training
G1	9.500 ± 1.834	32.867 ± 8.823	1.368 ± 0.124	17.264 ± 1.787	4.500 ± 1.679
G2	14.778 ± 1.856	54.733 ± 10.983	1.588 ± 0.088	21.493 ± 2.416	9.222 ± 2.819

The evaluations were conducted by the principal investigator, with assistance from artistic gymnastics coaches from the Molins de Rei Gimnàs Club who were familiar with the tests. The tests were performed during training sessions, following an initial warm-up that included general mobility exercises, active and passive flexibility, specific postures, and lumbo-pelvic activation/stabilization.

Five tests were conducted over two different days, during the middle of the competitive period. On the first day, two flexibility tests were recorded. On the second day, the execution of the handstand was recorded on video; in FX, on BB (20 centimeters high and 10 centimeters wide), and on UB (15 centimeters high). Before each evaluation, the gymnasts were given specific instructions and allowed time for familiarization with the procedures.

1) Shoulder flexibility test from the Age Group Program (Fink et al., 2021):

The gymnast stands with legs extended against a handstand bar, holding a club firmly with hands shoulder-width apart behind the bar. The distance between the bar (the edge closest to the gymnast) and the club is measured in centimeters. A score between 1 and 10 is given based on the centimeters achieved, as detailed in the test table (Fink et al., 2021) (Figure 1).

2) Shoulder flexibility test from GFMT (The Gymnastics Functional Measurement Tool), Sleeper et al., (2012; 2016).

The evaluation was conducted carefully following the "Instructions for the Administration of the GFMT." The gymnast lay face down on the floor with a cane in her hands and raised her arms, extended to their maximum height. The final result was determined by measuring the height reached and relating it to the length of the gymnast's arm (Figure 2). A score between 0 and 10 was then assigned based on the obtained result.

3) The handstands were recorded using a Samsung Galaxy S20 Ultra LTE mobile phone with software version 12.0.01.6. The recordings were made from the sagittal plane with a white wall background, positioned 4.85 meters from the center of the support and at a height of one meter (Rohleder & Vogt, 2019). A line was drawn in front of the

gymnast for hand support as a reference. Each gymnast started the handstand from the side that allowed them to analyze their dominant side in relation to the leg used to take the first step. The instructions were to reach the handstand position, bring the feet together as aligned as possible, and descend under control to the starting position. Each gymnast made at least three attempts, with the best attempt being maintained for analysis.

Markers were placed at the following anatomical landmarks to identify angles of the different segments in the sagittal plane for subsequent analysis (Gautier, 2007): 1) wrist (styloid-ulna process), 2) shoulder (posterior deltoid), 3) hip (greater trochanter of the femur), 4) knee (lateral epicondyle of the femur), 5) ankle (apex of the fibula or lateral malleolus) (Rohleder & Vogt, 2019) (Figure 3A). The optimal handstand position for assessment was determined at the moment when the movement began to reverse to return to the starting position (Masser, 1993; Rohleder & Vogt, 2018b). The Kinovea analysis software, version 0.9.5, was used to observe and analyze performance in the handstand.

A) °H (Figure 3B). The shoulder joint angle was recorded in degrees and segments 1-2-3 considered.

B) AJS (Figure 3C). A screenshot of the handstand at its optimal point was captured, and a handstand line was drawn from the support (wrist joint). Using the five anatomical landmarks marked on the gymnasts and the handstand descriptions proposed by Di Santo (1997) and Bessi (2016), the analysis was conducted by evaluating the alignment of the segments (A).

Figure 1. Age Group Flexibility Test, FIG; Age Group High Competition Development Program for Women's Artistic Gymnastics.

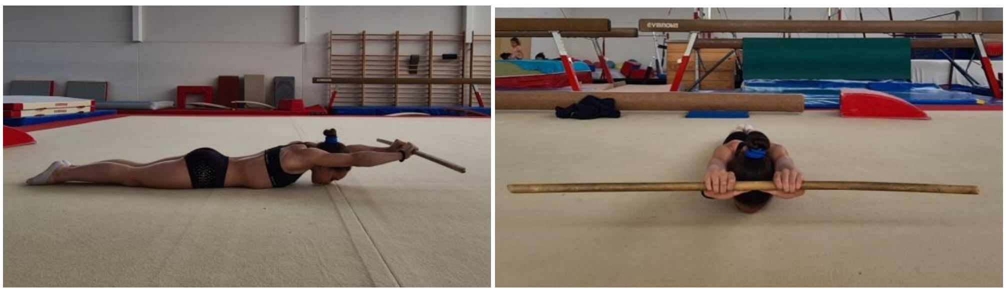

Figure 2. Shoulder Flexibility Test GFMT.

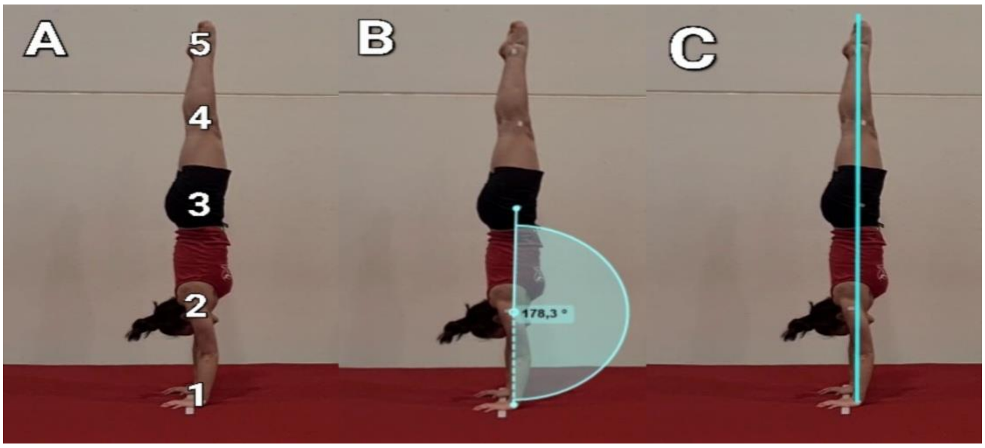

Figure 3. Evaluation of the handstand in the different apparatuses; F, BB and UB.
Note:
A) Joint segments marked for evaluation, numbered 1 to 5.
B) Shoulder joint angle.
C) Number of segments aligned.

A descriptive analysis (mean, standard deviation, and minimum/maximum range) was conducted for each group and their corresponding evaluations. The normality of the variables was assessed using the Shapiro-Wilk test, and homoscedasticity was checked with the Levene test where appropriate. Based on these results, differences between groups were analyzed using either the Student's t-test, Student's t-test with Welch correction, or the Mann-Whitney U test. Effect sizes were determined using Cohen's d or the rank biserial correlation coefficient, respectively.

To examine the relationships between tests, the normality of the distribution was verified using the Shapiro-Wilk test for the results of each flexibility test (independent variables) and the performance in the handstand (dependent variables). The Pearson or Spearman correlation coefficient, depending on the distribution, was used to observe the associations between the variables. Statistical significance was set at $p<0.05$. Statistical analyses were performed using JASP software, version 0.16.0.0 (Department of Psychological Methods, University of Amsterdam, Netherlands).

RESULTS

When comparing the results between G1 and G2, significant differences were found in three of the eight evaluations conducted (Table 2) (Figure 4).

For the GFMT test, one of the samples did not fit a normal distribution (W G1 = 0.859; p = 0.048; W G2 = 0.930; p = 0.481). Statistically significant differences were observed in favor of G2, which achieved higher scores (U = 21,000; p = 0.018) with a large effect size (rb = 0.611).

For the FIG test, one of the samples did not fit a normal distribution (W G1 = 0.931; p = 0.395; W G2 = 0.505; p < 0.001). Statistically significant differences were found in favor of G2, which scored higher (U = 23.500; p = 0.026) with a large effect size (rb = 0.565).

For AJS in the handstand on BB, both samples fit a normal distribution (W G1 = 0.900; p = 0.156; W G2 = 0.892; p = 0.208) and met the assumption of homoscedasticity (F = 0.086; p = 0.773). Statistically significant differences were found in favor of G2, which achieved higher scores (t = -2.175; p = 0.043), with a 95% confidence interval between -2.076 and -0.035 points, and a very large effect size (d = -0.955).

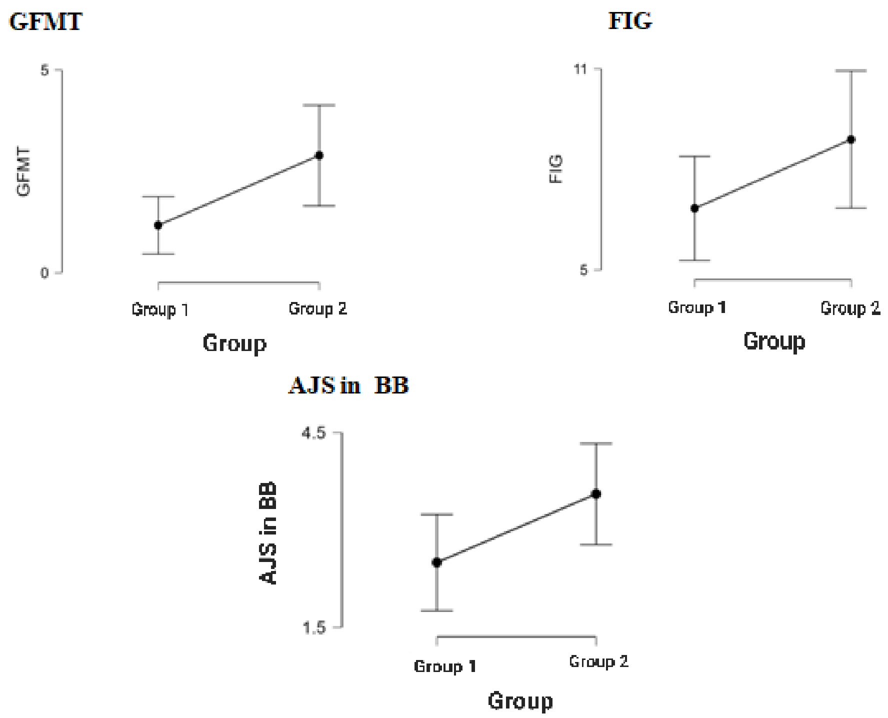

Figure 4. Statistically significant differences between G1 and G2 in the “GFMT / FIG” tests and the performance evaluations in the “AJS in BB” handstand.

Table 2.
Values achieved in the evaluations and differences between both groups.

	G1		G2					
Test	Mean ± SD	Range	Mean ± SD	Range	Estatistical	p	i.c 95%	d / rb
GFMT	1.167 ± 1.115	0 – 3	2.889 ± 1.616	0 – 5	21.000 [c]	0.018*		0.611
FIG	6.833 ± 2.443	3 – 10	8.889 ± 2.667	2 – 10	23.500 [c]	0.026*		0.565
°H - F	176.000 ± 5.099	167 – 184	178.778 ± 3.993	172 – 183	-1.350 [a]	0.193		0.595
AJS F	2.917 ± 1.240	1 – 5	3.889 ± 0.782	3 – 5	27.000 [C]	0.052		0.500
°H BB	176.667 ± 4.677	168 – 184	180.444 ± 7.892	171 – 195	-1.278 [b]	0.225		0.582
AJS BB	2.500 ± 1.168	1 – 5	3.556 ± 1.014	2 – 5	-2.165 [a]	0.043*	-2.076/-0.035	0.955
°H UB	178.000 ± 8.202	166 ± 194	180.111 ± 6.827	172 – 195	-0.626 [a]	0.539		0.276
AJS UB	2.167 ± 1.030	1 – 4	2.778 ± 0.833	2 – 4	36.000 [C]	0.194		0.333

*p < 0,05 statistically significant relationships.
[a] t de Student; [b] t de Student with the correction of Welch; [c] U de Mann-Whitney.

Finally, the associations and statistically significant relationships between the results of the GFMT/FIG tests and handstand performance (°H and AJS) on FX, BB, and UB are summarized (Table 3). Two statistically significant relationships were found in G1, while no statistically significant relationships were observed in G2 (Figure 5).

In G1, there was a statistically significant and directly proportional association between GFMT and °H in UB (r = 0.655; p = 0.021; 95% CI: 0.893 to 0.129). Additionally, there was a statistically significant and directly proportional association between FIG and °H in BB (r = 0.742; p = 0.006; 95% CI: 0.923 to 0.294).

Two associations approached significance: between FIG and °H in the handstand on UB (r = 0.553; p = 0.062), and between FIG and °H in the handstand on BB (r = 0.642; p = 0.062). Both associations showed a trend towards significance but were not statistically significant.

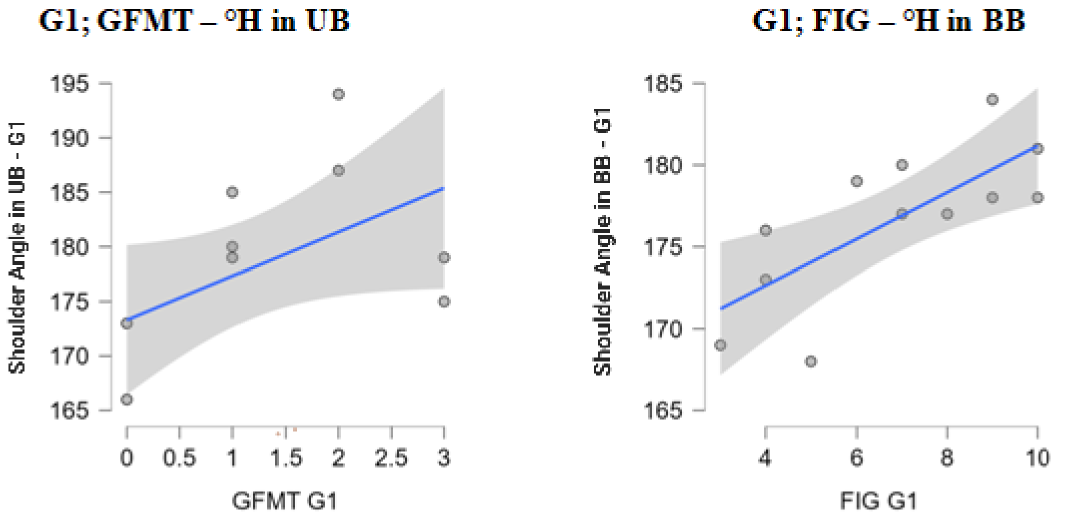

Figure 5. Statistically significant relationships between flexibility tests and performance evaluations in handstand.
A) GFMT / Shoulder angle in UB, G1.
B) FIG / Shoulder angle in BB, G1.

Table 3.
Significant relationships and directly or inversely proportional associations between flexibility tests and performance evaluations in the handstand.

	GFMT G1 r / p	FIG G1 r / p	GFMT G2 r / p	FIG G2 r / p
°H F	(+) 0.224 a / 0.484	(+) 0.224 a / 0.484	(+) 0.015 a / 0.969	(+) 0.069 b / 0.860
AJS SU	(-) 0.055 a / 0.866	(-) 0.275 a / 0.387	(+) 0.286 a / 0.456	(+) 0.232 b / 0.548
°H BB	(+) 0.343 a / 0.275	(+) 0.742 a / 0.006**	(+) 0.426 a / 0.253	(+) 0.642 b / 0.062
AJS BB	(-) 0.349 a / 0.266	(-) 0.223 a / 0.486	(+) 0.042 a / 0.914	(-) 0.036 b / 0.927
°H UB	(+) 0.655 b / 0,021*	(+) 0.553 a / 0.062	(-) 0.078 a / 0.842	(+) 0.232 b / 0.548
AJS UB	(-) 0.185 a / 0.565	(+) 0.337 a / 0.248	(+) 0.258 a / 0.503	(-) 0.464 b / 0.209

*p < 0,05; **p < 0,01 Statistically significant relationships.
(+) Directly proportional association; (-) Inversely proportional association.
[a] Pearson's r; [b] Spearman's r_S.

DISCUSSION

This study aimed to investigate the relationship between shoulder joint flexibility in flexion, handstand °H, and AJS in different apparatuses for child and adolescent gymnasts, and to compare performance between the two age groups. The results revealed significant differences favoring G2, which achieved better results in the evaluations. Significant differences were observed in the GFMT and FIG tests between the groups.

These findings contrast with those of Gómez-Landero Rodríguez et al. (2013), who evaluated flexibility in two groups of female trampolinists: under-15 (11.44 ± 1.23 years) and absolute (16.1 ± 2.02 years). They found no significant differences in the active shoulder flexion range, with results of 184.91° ± 13.97 and 184.56° ± 21.02, respectively, for each group. Their shoulder flexibility test, which is similar to the GFMT in terms of the athlete's position, measures degrees rather than centimeters of distance from the floor and arm length. Their study concluded that flexibility may not be an exclusively determining factor in performance for trampolinists, unlike other gymnastic disciplines.

Regarding the comparison of handstand performance, Kochanowicz et al. (2018) found that young male gymnasts (13.9 ± 0.7 years) exhibited significantly higher displacements of the center of pressure in both the medial-lateral and anteroposterior axes compared to elite adult gymnasts (23 ± 3 years). This aligns with our findings, which show statistically significant differences in AJS in the BB handstand in favor of G2. The more experienced G2 gymnasts appear to achieve greater control and body awareness, starting from the support and demonstrating better shoulder location and stability. When the base of support is small, an effective shoulder strategy becomes crucial (Hedbávný et al., 2013). As fitness levels improve, the quality and stability of the handstand are less influenced by external factors (Omorczyk et al., 2018).

Furthermore, Kochanowicz et al. (2019) highlighted that in floor handstands, parallel bars, and rings, the muscles with the highest EMG activity—exceeding 30% of the maximum voluntary contraction—are those of the upper limbs. The greatest EMG activity was observed on rings, the most unstable apparatus, where shoulder muscles exhibited increased activity. Significant differences were found in only five of the 13 muscles studied when comparing young gymnasts (13.9 ± 0.7 years) with adults (25.6 ± 3.94 years), who showed lower muscle activation. In our study, G2 demonstrated superior mastery and control, reflected in higher scores for °H (closeness to 180°) and AJS across all handstands. Although a statistically significant difference was found only in AJS of the BB handstand ($p = 0.043$), AJS in the FX handstand also tended towards significance ($p = 0.052$).

In the AJS of UB, the results showed the greatest parity between the two groups. This can be attributed to the inherent complexity of the UB handstand, where achieving and maintaining virtuosity is challenging due to the nature of the support and base. In routines and training, the handstand on UB is often used as a transitional position rather than one requiring sustained maintenance, unlike the handstands on FX and BB, where maintaining the position is more common, especially during developmental and training stages.

Although Kochanowicz's studies differ from ours in terms of gender, age, and developmental stages of the gymnasts, it is reasonable to assume that more years of training contribute to better control and technical mastery of the handstand. For more experienced athletes, maintaining an inverted position may become more "natural" compared to less experienced gymnasts (Omorczyk et al., 2018).

In general, flexibility is positively related to performance in gymnastics. León-Prados et al. (2011) found statistically significant relationships between active and passive flexibility tests and performance on three men's gymnastics apparatuses. They observed significant correlations between flexibility in hip flexion and performance on the parallel bars ($r = -0.842^{**}$) and the fixed bar ($r = -0.696^{*}$), as well as between flexibility in hip abduction and performance on the pommel horse ($r = 0.652$), parallel bars ($r = 0.629$), and horizontal bar ($r = 0.815$). Furthermore, flexibility emerged as a key quality in the fitness profile results, identified as one of the determinants of gymnastics performance (Mkaouer et al., 2018).

Referring to the relationships between GFMT/FIG results and performance evaluations in the handstand, only two statistically significant relationships out of the 24 proposed were found. These were between GFMT and °H in UB for G1 ($p = 0.021$) and between FIG and °H in BB for G1 ($p = 0.006$). These findings show some similarity to those of Sleeper et al. (2012), who did not find significant correlations between the competitive level of female gymnasts and the results of the GFMT shoulder flexibility test, although the results were close to significance ($p = 0.05$). However, they did find a significant correlation between test results and age ($p = 0.00$). Conversely, Sleeper (2016) identified statistically significant relationships between GFMT results and competitive level ($p = 0.01$) and age ($p = 0.002$) in male gymnasts.

In the current study, GFMT and FIG generally showed a directly proportional association with handstand performance measured in °H. This means that as flexibility scores increase, the °H in the handstand approaches 180°. This trend was observed for G1 across both tests and all handstands (F, BB, and UB), totaling six associations. For G2, only one association was inversely proportional (between GFMT and °H in PA), while the remaining five associations were directly proportional.

McLaren (2015) identified statistically significant relationships between shoulder angle and wrist angle during the impact phase of a backward flic-flac ($p = 0.04$), noting that greater shoulder amplitude reduces wrist hyperextension. This suggests that increased shoulder flexion amplitude can be beneficial for achieving optimal positioning during inverted supports, such as handstands or temporary positions like flic-flacs.

Regarding the association between GFMT/FIG and AJS, the results varied between groups. In G1, there were more inversely proportional associations, indicating that as flexibility test scores increased, AJS decreased. Specifically, G1 had five inversely proportional associations out of a total of six, with the relationship between FIG and AJS in UB being the only directly proportional association.

In contrast, G2 showed fewer inversely proportional associations, with only two out of six evaluated relationships being inversely proportional. These were the associations between FIG and AJS in BB and UB.

To maintain balance, gymnasts initially use a wrist strategy, followed by a shoulder strategy, and will resort to a hip strategy in cases of major disturbances or imbalances (Kochanowicz, 2018). Experience, maturity, and technical mastery over the years likely enhance postural control and alignment of body segments from the support to the ankles. Increased flexibility in younger gymnasts can lead to greater swings and disturbances that are harder to control. Consequently, achieving a shoulder angle of 180° in the handstand does not always ensure proper alignment of the other joint segments. As Gamble (2021) suggests, it is crucial to prioritize both mobility and neuromuscular training to help athletes control their range of motion while maintaining postural and joint integrity.

Regarding flexibility, it is noteworthy that in both groups, some gymnasts achieved the ideal score of "10" on the FIG test, while the maximum score on the GFMT test was only "5" out of a possible "10" points. This suggests that the GFMT may be a more demanding measure of flexibility. This distinction could be an important consideration for future studies or for coaches when evaluating their gymnasts.

Future studies could benefit from investigating which joint segments are most likely to align or misalign during handstands, as well as exploring the underlying reasons for these patterns. The data provided by this study offer a foundation for further exploration into the complex and multifaceted aspects of handstand performance.

LIMITATIONS OF THE STUDY

It is important to note that the sample size was small, and there may have been greater variations in technical level within Group 1 (ages 7 to 12) compared to Group 2 (ages 13 to 17). These differences in technical proficiency could have influenced performance, particularly on asymmetric parallel bars, which may have presented the greatest challenge.

CONCLUSIONS

Significant differences were observed between the two groups in the shoulder flexibility tests, with adolescent gymnasts generally achieving better scores than child gymnasts. However, significant differences were noted in only one of the performance evaluations—the AJS in the balance beam handstand.

Regarding the relationships between flexibility tests and performance evaluations, only two significant associations were found for Group 1: between GFMT and °H in the uneven bars handstand, and between FIG and °H in the balance beam handstand. For younger gymnasts, it is crucial to focus not only on shoulder flexibility but also on control and postural awareness to ensure optimal alignment and positioning of the shoulder in various elements for effective performance.

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JUMP PERFORMANCE IN TRAMPOLINE ATHLETES AND HOW TO MEASURE IT: DEVELOPING A REPEATED JUMP TEST

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Abstract

A competitive trampoline routine consists of ten scored jumps on which trampoline gymnasts need to exhibit an adequate strength endurance performance of their lower extremities. These strength endurance requirements are assessed with "Repeated Jump Tests" (RJT). However, existing tests are not designed for trampolining, but rather for game sports. Such tests aim, for example, at different number of repetitions and for minimizing ground contact time, thus lacking the specific repetitions and intensity of a trampoline routine. Therefore, the aim of this study is to develop a RJT specifically for trampolining that will assess jump height, performance decrement (PD) during RJT, and jump-to-jump fluctuations. Twenty-nine elite trampoline gymnasts (TR) from the junior national squad (JNS-TR; n = 21) and the senior national squad (SNS-TR; n = 8), 21 athletes from jump-intensive game sports (GS; comprising volleyball n = 15; handball n = 6), and 16 PE students (PE) completed the RJT consisting of twelve repeated jumps. Group differences were analyzed by ANOVA and trampoline squad differences via t-tests. Results showed that TR had a lower PD compared to GS and PE (p < .05). SNS-TR trampoline gymnasts show lower jump-to-jump fluctuations than JNS-TR trampoline gymnasts (p < .05). TR exhibited a superior performance in the RJT regarding PD compared to GS and PE. In conclusion, our RJT is proposed as a new tool for validly measuring repeated jump performance in trampoline gymnasts.

Keywords: *performance analysis, elite athletes, performance decrement, athletic performance.*

INTRODUCTION

Every year, the German Olympic Sports Confederation (DOSB) publishes a list of sports federations with the largest membership in Germany. For many years, the "Deutscher Turner-Bund" (German Gymnastics Association) has been the second most popular German federation (Deutscher Olympischer Sportbund, 2022). The disciplines it covers include gymnastics, artistic gymnastics, and trampoline gymnastics. In these disciplines, jumps induce significant mechanical strain on athletes' bodies during training and routines (Batista et al., 2016), requiring a high level of explosive jumping power and strength endurance (Jastrjembskaia & Titov, 1999). In trampolining competitions, athletes perform a routine lasting approximately 40 seconds that includes ten somersault movements of varying difficulty on a trampoline net (Jensen et al., 2013; Qian et al., 2020). Each somersault movement is scored based on difficulty, skill execution, horizontal displacement, and Time of Flight (ToF; Ferger et al., 2020). The ToF refers to the time interval between when the foot loses contact with the net and then it resumes contact after a successful movement (Fédération Internationale De Gymnastique, 2015), and serves as an objective evaluation criterion (Lenk et al., 2017). The importance of the ToF has increased in recent years, with Heinen and Krepela (2016) finding an increase in ToF when analyzing the senior World and World Age Group Championship individual finals between 2011 and 2015. Using this data, they found that ToF was the greatest contributor to trampoline scoring outcomes. Therefore, trampoline gymnasts (TR) must maintain their jump height throughout all jumps, reducing performance decrements (PD) during the routine while also avoiding fluctuations between jumps. This is essential for two reasons: first, to perform difficult movements more easily, and second, to achieve a high score according to the ToF criterion. In addition to technical components, the physical properties of the lower extremities (particularly strength endurance) play a crucial role in accomplishing this goal (Meckel et al., 2015). Consequently, this study focused on strength endurance.

To measure the strength endurance component mentioned above, "Repeated Jump Tests" (RJTs) are commonly used. Previous studies have explored different approaches to structuring an RJT depending on the specific requirements being investigated. In performance testing, RJTs often involve six sets of six consecutive jumps with 30-second pauses between sets (Meckel et al., 2015; Segev & Meckel, 2020). Another test, described by Harper et al. (2011), is the 10/5 RJT, in which athletes complete ten maximum rebound jumps with minimal ground contact times. However, these RJTs do not accurately reflect the demands of a trampoline routine, which consists of ten jumps with relatively longer contact times. Therefore, the 6×6 and 10/5 RJTs are more suited to game sports that involve fewer consecutive jumps, such as volleyball or handball. Current RJTs either focus on jump-intensive sports like handball or volleyball, which do not adequately address the specific needs of trampolining, or they require specialized equipment, as in the test by Dyas et al. (2021). This test, known as the "20-maximum trampoline jump test," involves 20 jumps on a trampoline, with measurements of ToF, force, horizontal displacement, and contact time. While this test is highly specific to trampolining, it necessitates a trampoline and a ToF measuring system, which may not be available in all locations. Compared to game sports athletes (GS), trampoline gymnasts (TR) must not only achieve maximum jump height but also maintain this height consistently throughout their routine while minimizing jump-to-jump fluctuations. Performance decrement (PD), which refers to the decrease in jump height over a defined test period, may be the most critical parameter in this context (Meckel et al., 2015). While PD is a key focus in Repeated Sprint Tests, it has not been as extensively emphasized in RJTs (Morin et al., 2011). For instance, Glaister et al. (2008) developed eight different formulas to represent the decline in sprint performance over time. This decline can be calculated as the percentage increase in time by comparing the first and last sprints to the optimal performance (i.e., the number of sprints multiplied by the fastest sprint time) and actual performance (i.e., the sum of all sprint times). For a more detailed explanation, see Glaister et al. (2008). The authors concluded that the formula incorporating both optimal and actual sprint performance was the most suitable. Girard et al. (2011) supported this conclusion in their review of Repeated Sprint Ability, recommending that all sprints be included in the formula derivation, as PD was found to be minimally affected by outliers. However, they also noted that each formula has its own strengths and limitations. In summary, reporting PD appears to be a valid method for quantifying strength endurance.

To better reflect the strength endurance characteristic and to initiate and accelerate fatigue, the RJT has previously been performed with additional load (Hermes et al., 2019; Sevene et al., 2017). Loaded jumps have been shown to exert greater stress on the neuromuscular system (Natera et al., 2020). Additionally, Taber et al. (2023) demonstrated that using additional load in countermovement jumps (CMJ) results in a higher eccentric braking impulse and force. It is assumed that this mirrors the increased eccentric load during the jumping movement on a trampoline net (Márquez et al., 2013; Matsushima, 2024). Moreover, the increased stress from the loaded repeated jumps (RJs) is designed to induce performance decrement (PD) more quickly. With the selected additional load, PD can be achieved earlier, leading to an RJT that is economical, quick, and easy to perform.

The main purpose of this study is to develop a valid and reliable RJT for trampolining that examines the physical requirements stated above. To achieve this, the following research questions are addressed:

1. To evaluate whether the RJT distinguishes between TR, GS, and PE students.
2. To investigate different formulas for quantifying PD over time.
3. To assess the reliability of the RJT in PE students across two different measurements.

It is expected that TR will not achieve the highest jump heights, as participants in GS belong to jump-intensive sports such as volleyball and handball, where significantly higher values are anticipated (Borràs et al., 2011; Hermassi et al., 2019; Pereira et al., 2018; Sattler et al., 2012). However, TR are expected to achieve a lower PD and the lowest jump-to-jump fluctuations during the RJT, as these factors are more closely aligned with the demands of trampolining gymnastics.

METHODS

The study was using a cross-sectional design. Prior to testing, participants received detailed written and verbal information about the potential benefits and risks associated with the study. Written informed consent was obtained from all participants (and from parents for athletes under 18 years old). The study was carried out in accordance with the recommendations of the local ethics committee (2021–30, June 28th, 2021), with written informed consent obtained from all participants in line with the Declaration of Helsinki.

A total of 66 athletes (M_{age} = 20.15 ± 4.31 years) from three different subgroups were measured. The subgroups were TR (*n* = 29; M_{age} = 18.62 ± 3.78 years), GS (*n* = 21; M_{age} = 18.71 ± 2.43 years), and PE (*n* = 16; M_{age} = 24.88 ± 3.77 years); 60.6% of all participants were males. The TR were in either the junior (JNS-TR; *n* = 21, M_{age} = 23.13 ± 1.87) or senior Germany national squad (SNS-TR; *n* = 8, M_{age} = 16.90 ± 1.90). The squads refer to the German elite sports system. Athletes in the JNS-TR are typically under the age of 18, and compete, for instance, at youth championships such as the Youth World Championships. SNS-TR athletes are usually older, take part in senior competitions and can qualify for the Olympics. GS were either in Germany’s junior national volleyball squad or players in a German second division handball team. PE were registered for a Master of Sports Science degree.

Upon arrival and after being briefed on the testing protocol, participants were weighed using a Multi-Scale-Analysis device (Bomann, Germany) to determine their additional load for the RJT (details provided below). Athletes then performed a 15-minute warm-up that included dynamic and jump-specific exercises before beginning the test protocol. All tests were conducted by the same two researchers according to a standardized manual. All jumps were performed on the ground using the OptoGait© system (Microgate, Italy) for data recording. The system has demonstrated strong validity (ICC = .99) and excellent test-retest reliability (ICC = .98), making it a suitable method for measuring jump height in field tests (Glatthorn et al., 2011).

For familiarization, participants performed three CMJs (Countermovement Jumps) ranging from submaximal to maximal effort. During these jumps, the following instructions were emphasized: keep hands on hips at all times, perform a direct CMJ without pausing to a self-chosen depth, maintain extended legs and feet during the flight phase, avoid jumping forward or backward, and land with feet extended as during take-off.

The test protocol included two normal CMJs and two loaded CMJs (SingleJ). The loaded jumps were performed using a weight vest that added 20% of the participant's body weight. If the two jumps within a condition differed by more than 10%, a third trial was conducted, which occurred with approximately 10% of the participants.

For the repeated jumps, athletes were asked to perform twelve CMJs in a repeated manner, guided by an audio signal for each jump. As shown in Figure 1, a signal sounded to initiate each CMJ every 3 seconds. The signal was the German word "VOLL," meaning "full," which was intended to motivate the participants to perform their best possible jump each time. After landing, participants were encouraged by the test administrators to straighten up, if necessary, so they always started the next jump in an upright position. They were not informed about the number of remaining jumps during the set. After completing the twelve RJs, testing was stopped. As with the CMJs, jump height was measured via the time-of-flight calculation. For further analysis, the jump height of each jump was recorded. For test–retest reliability, 16 PE participants were measured again one week later, with the procedure carried out exactly as in the first measurement. There were no dropouts between the first and second measurements.

Figure 1. RJs executed with additional load. Figure shows one RJ movement.

Previous studies have used different approaches to calculate the decrease in performance (Glaister et al., 2008). The eight formulas each applied different methods to calculate PD. They are displayed below.

In formulas 1 and 2, only 10 jumps and the highest single loaded CMJ (SingleJ) were used.

$$F1 = (((\text{sum of RJ 3 to 12}) \div (\text{SingleJ} \times 10)) \times 100) - 100$$

$$F2 = (((\text{sum of RJ 2 to 11}) \div (\text{SingleJ} \times 10)) \times 100) - 100$$

Formulas 3-5 refer to 10 selected or all jumps, and the highest jump of single loaded CMJ or repeated jumps (MaxJ).

$$F3 = (((\text{sum of all RJ}) \div (\text{MaxJ} \times 12)) \times 100) - 100$$

$$F4 = (((\text{sum of RJ 2 to 11}) \div (\text{MaxJ} \times 10)) \times 100) - 100$$

$$F5 = (((\text{sum of RJ 3 to 12}) \div (\text{MaxJ} \times 10)) \times 100) - 100$$

Formulas 6-8, similar to formulas 3-5, include 10 selected or all jumps as actual performance. However, in F6-F8, the highest jump among the twelve repeated jumps (MaxRJ) is used as the ideal performance.

F6 = (((sum of all RJ) ÷ (MaxRJ × 12)) × 100) - 100

F7 = (((sum of RJ 2 to 11) ÷ (MaxRJ × 10)) × 100) - 100

F8 = (((sum of RJ 3 to 12) ÷ (MaxRJ × 10)) × 100) - 100

All statistical operations were performed using SPSS (SPSS Version 29.0.0.0). Values are presented as means (M) ± standard deviations (SD), and normal distribution was assessed using the Shapiro–Wilk test. To quantify the jump height achieved, the mean value of all twelve RJs was calculated (MeanRJ). PD was calculated using the eight formulas presented. To provide more detailed information about fluctuations between each RJ, a jump-to-jump evaluation was performed. This was calculated using Sample Entropy (SampEn) in MatLab (MathWorks, 2023) with the “EntropyHub” toolkit created by Flood and Grimm (2021). The following variables were used to calculate SampEn: embedding dimension m = 2, sequence length N = 12, radius threshold r = 0.2×SD, according to recommendations by Mayer et al. (2014). Bm(r) is the probability that sequences match for m points, while Am(r) is the probability that two sequences match for m + 1 (Kupper et al., 2020).

$$SampEn(m, r, N) = -\ln\left(\frac{A^m(r)}{B^m(r)}\right) \qquad (1)$$

Differences in the average jump height of the RJs (MeanRJ), the PD for each of the eight formulas, and the jump-to-jump fluctuations between the subgroups were analyzed using a one-way ANOVA. If a significant difference was found, Tukey's HSD test was used to identify significant differences between the subgroups. Since the distribution of the SampEn data for TR was found to be dichotomous, a squad comparison between SNS-TR and NJS-TR of the jump-to-jump fluctuations was conducted in addition to the comparison of sports. Based on the descriptive data, lower jump-to-jump fluctuations in the SNS-TR were expected, so a one-tailed t-test was used. Test–retest reliability was analyzed using Pearson’s *r* between both measurements of PE. Effect sizes were interpreted according to Cohen (1988). The significance level was set at $p < .01$. Figures were created using R (R-4.3.2) within RStudio (2023.12.0.369; Posit Team, 2023).

RESULTS

The *M* and SD for the RJs, PD for all formulas and jump-to-jump fluctuations for all subgroups and squad affiliations are displayed at the end of the section in Table 1.

Differences Between Groups:

Jump height: Significant differences in the average jump height of the RJs were found between the subgroups ($F(2, 63) = 15.25$, $p < .001$). Post-hoc tests revealed significant differences between the GS and TR ($p < .001$), and between the GS and PE ($p < .001$).

PD: TR achieved a lower PD in every formula (see Table 1). The ANOVA revealed significant differences when using formulas F1 ($F(2, 63) = 7.38$, $p = .001$), F2 ($F(2, 63) = 7.83$, $p < .001$), F3 ($F(2, 63) = 4.96$, $p = .010$), F4 ($F(2, 63) = 5.33$, $p = .007$), F5 ($F(2, 63) = 8.73$, $p < .001$) and F8 ($F(2, 63) = 6.78$, $p = .002$). Tukey´s HSD test showed significant differences between the TR and PE students when using F1 ($p = .002$), F2 ($p = .002$), F3 ($p = .015$), F4 ($p = .010$), F5 ($p = .001$), and F8 ($p = .017$). Significant differences between TR and GS were found when using F1 ($p = .024$), F2 ($p = .010$), F5 ($p = .007$), and F8 ($p = .005$).

Jump-to-jump fluctuations: To compute SampEn, the radius threshold was set at $r = 1.12$ (0.2×SD, SD = 5.62). There was no significant difference between all three subgroups ($F(2, 63) = 0.715$, $p = .493$). Differences between the subgroups in jump height, PD, and jump-to-jump fluctuations are shown in Figure 2

Table 1
Means and standard deviations for the jump height, performance decrement, and jump-to-jump fluctuations in the RJT divided into the subgroups trampoline gymnasts (TR), games sports athletes (GS) and PE students (PE) as well as squad levels junior national squad (JNS-TR) and senior national squad (SNS-TR)

Sports		Jump height	Performance decrement								Jump-to-jump fluctuations
		MeanRJ	F1	F2	F3	F4	F5	F6	F7	F8	SampEn
TR	Total (*n* = 29)	22.6 ± 4.6	-8.64 ± 6.66	-7.95 ± 6.73	-10.41 ± 4.35	-10.05 ± 4.67	-9.79 ± 4.25	-6.90 ± 2.29	-6.54 ± 2.60	-6.26 ± 2.04	0.497 ± 0.296
	JNS-TR (*n* = 21)	22.2 ± 5.0	-9.05 ± 7.00	-8.20 ± 6.94	-10.60 ± 4.60	-10.15 ± 5.00	-9.86 ± 4.43	-7.10 ± 2.51	-6.64 ± 2.88	-6.33 ± 2.27	0.652 ± 0.301
	SNS-TR (*n* = 8)	23.8 ± 2.9	-7.58 ± 5.95	-7.30 ± 6.54	-9.92 ± 3.84	-9.80 ± 3.97	-9.61 ± 4.02	-6.39 ± 1.58	-6.27 ± 1.83	-6.07 ± 1.39	0.328 ±0.215
GS	Total (*n* = 21)	28.2 ± 4.1	-13.11 ± 5.56	-13.03 ± 5.84	-13.27 ± 4.79	-13.10 ± 5.06	-13.89 ± 5.18	-8.52 ± 3.33	-8.35 ± 3.55	-9.18 ± 3.83	0.603 ± 0.485
PE	Total (*n* = 16)	20.2 ± 5.2	-15.05 ± 4.03	-14.40 ± 3.87	-14.30 ± 3.67	-14.40 ± 3.87	-15.05 ± 4.03	-8.23 ± 3.42	-8.34 ± 3.56	-9.04 ± 3.80	0.779 ± 0.020

Note. MeanRJ is the mean jump height over all twelve RJs; F1–F8 denote all the PD formulas used; SampEn (r = 1.12) describes the jump-to-jump fluctuations.

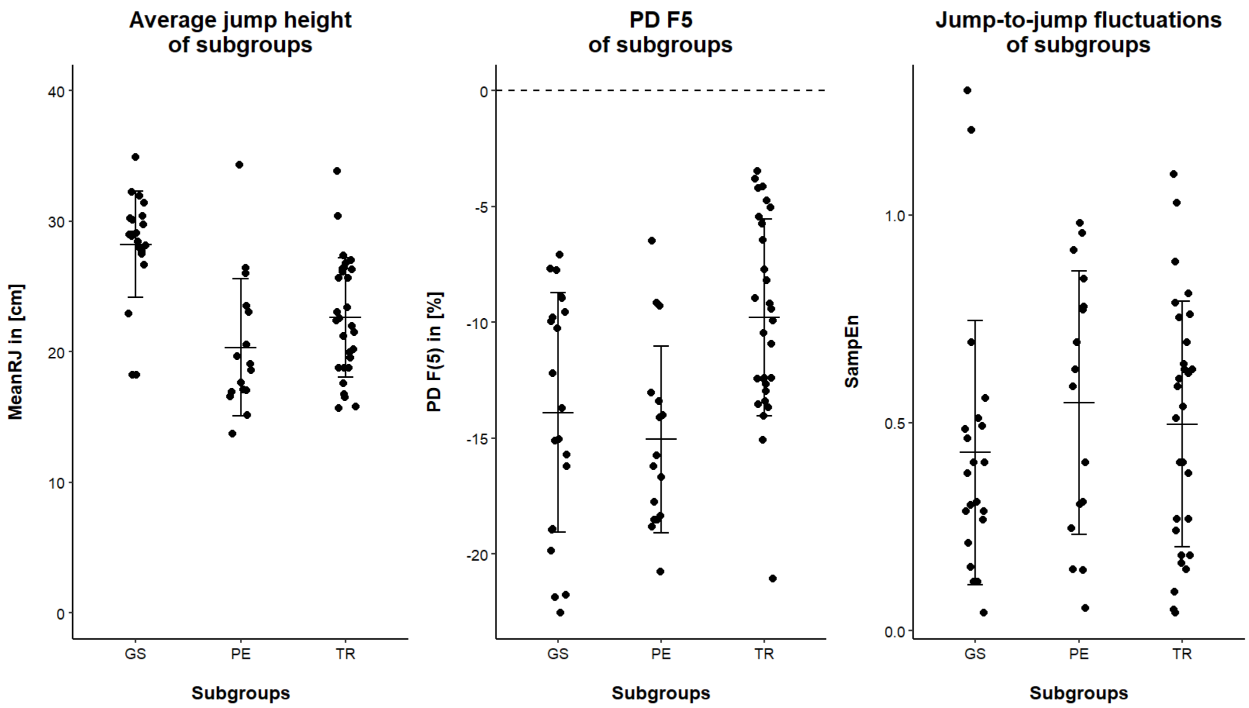

Figure 2. Subgroup comparisons in the jump height, jump-to-jump fluctuations, and performance decrement when using formula F5.

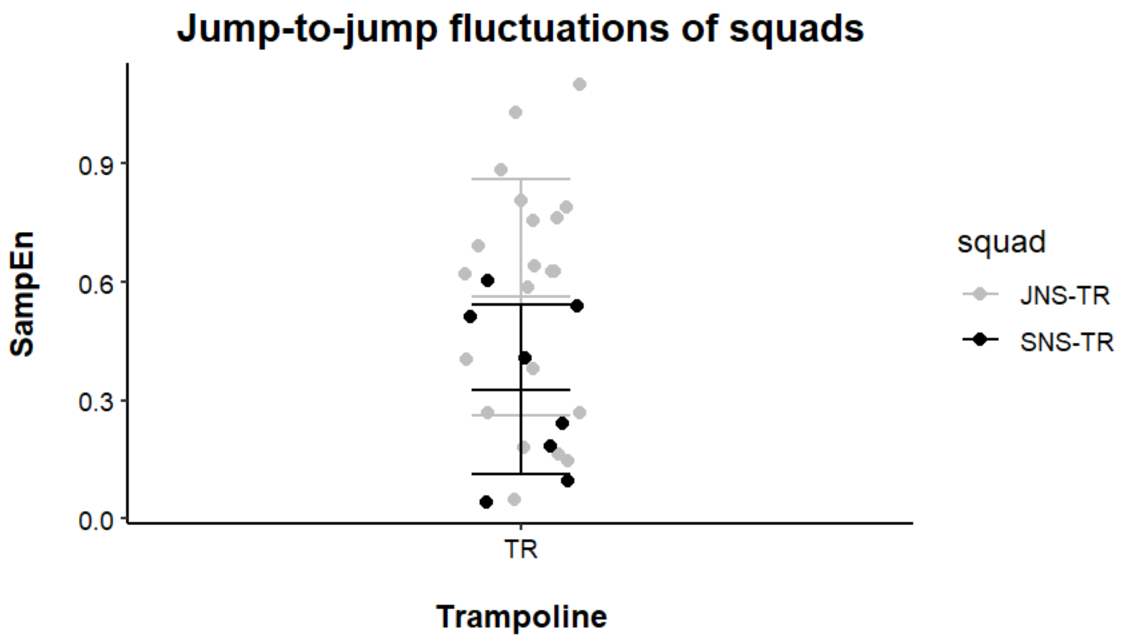

Figure 3. Dichotomous distribution of jump-to-jump fluctuations in trampoline squads.

Differences Between Squads:

Jump-to-jump fluctuations: After finding a dichotomous distribution of the jump-to-jump fluctuations within the TR, which was due to lower jump-to-jump fluctuations of SNS-TR compared to JNS-TR, a one-tailed *t*-test was used to identify differences within the TR. The distribution within the TR is presented in Figure 3. The SNS-TR showed significantly lower jump-to-jump fluctuations compared to the NJS-TR ($t(27) = 2.00$; $p = .028$).

Test-Retest Reliability (PE Students)

Jump height: Reliability, calculated using the MeanRJ, showed a strong positive correlation between Measurement 1 and Measurement 2 ($r = .989$, $p < .001$).

PD: In addition, another calculation of reliability was performed when using all PD formulas. Pearson's *r* values obtained from all formulas ranged from $r_{F2} = .167$ ($p = .537$) to $r_{F5} = .384$ ($p = .151$), thus indicating a poor to moderate yet no significant correlation.

Jump-to-jump fluctuations: The SampEn for the test retest was calculated on the basis of the PE population using the radius threshold r = 1.05 (0.2×*SD*; *SD* = 5.26). The test–retest reliability of the jump-to-jump fluctuations showed a moderately positive correlation ($r = .432$, $p = .094$). A graphical representation of the respective test–retest reliability is shown in Figure 4

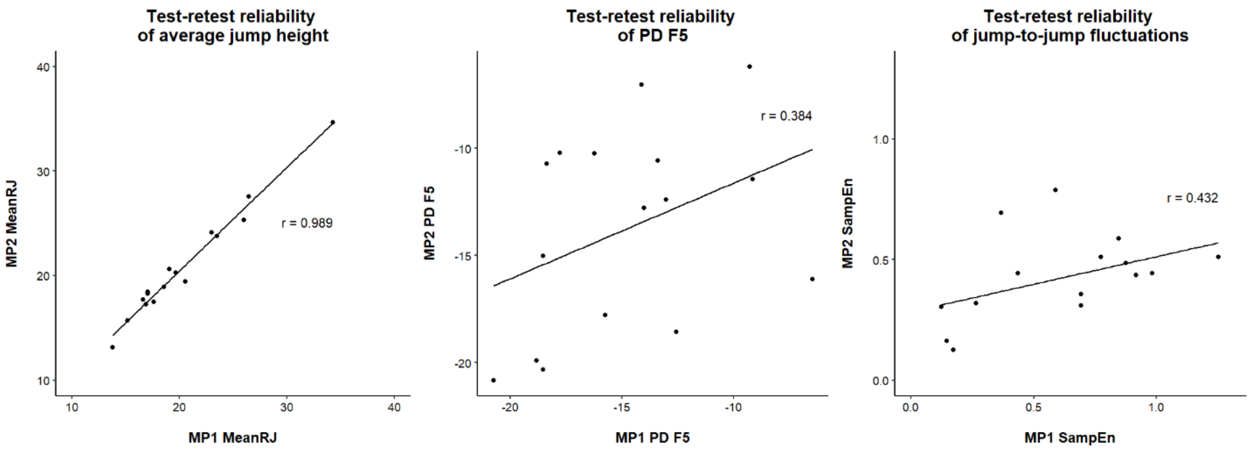

Figure 4. Test-retest reliability of the PE students via the MeanRJ, SampEn, and PD obtained from F5 using Pearson's r of each test–retest.
Note. The x-axis is defined as Measurement 1 (MP1) and the y-axis as Measurement 2 (MP2) of the variable under consideration.

DISCUSSION

In trampolining, athletes must be able to jump as high as possible and maintain their jump height at a high level throughout their routine while also avoiding jump-to-jump fluctuations. This requires adequate strength endurance in the lower extremities. Therefore, the main purpose of the present study was to develop a valid and reliable RJT specifically for trampolining. The sports group comparison shows that trampoline gymnasts (TR) achieve a lower PD than game sport athletes (GS) and PE students (PE). Our results indicate that, regardless of the evaluation formula chosen, different levels of experience in repeated jumping can be distinguished. Additionally, the test-retest reliability of the RJT was acceptable when mean jump height was considered.

Three groups with different preconditions were examined using the average jump height of the RJs, PD, and jump-to-jump fluctuations. Group comparisons between the trampoline gymnasts (TR), game sports athletes (GS), and PE students (PE) show that TR achieved a significantly lower PD compared to the other groups. This suggests that RJT is well-suited for trampolining, as a low PD indicates better maintenance of jump height and, therefore, greater strength endurance. Regarding the different formulas for calculating PD, the TR group consistently showed smaller PD compared to the other subgroups across all formulas, with significant differences occurring in Formulas F1, F2, F3, F4, F5, and F8.

As stated earlier, years of trampoline training enable trampolinists to meet the demands of repeated jumping, allowing them to maintain their jumping performance more consistently (Jensen et al., 2013). In contrast, all GS participants came from jump-intensive sports in which single, maximal, and explosive jumps are performed (Ortega-Becerra et al., 2018; Sattler et al., 2012). Consequently, while they need to achieve a maximal jump height, they may struggle to reproduce this in a series of jumps (Meckel et al., 2015). Given the significantly smaller PD observed in TR, the test appears to effectively assess the specific physical requirements of trampolining.

When analyzing jump height between groups, the results show significant differences, with GS achieving the highest average jump height during the RJ compared to TR and PE. This was expected since GS participants were from jump-intensive sports such as volleyball and handball (Borràs et al., 2011; Hermassi et al., 2019; Pereira et al., 2018; Sattler et al., 2012). Jastrjembskaia and Titov (1999) note that TR athletes specifically require more strength endurance in their lower extremities due to the sport's demands. Moreover, TR athletes must utilize the elastic capabilities of the trampoline net in their routines to achieve maximum flight time (Qian et al., 2020).

An exploratory data analysis revealed a different distribution of jump-to-jump fluctuations within the TR group, which was linked to squad affiliation. A post-hoc analysis identified significant differences in jump-to-jump fluctuations between the squads, with SNS-TR having significantly lower fluctuations than NJS-TR. Higher-level TR athletes, therefore, seem to exhibit more consistent jumps. A greater level of expertise in TR athletes appears to correspond to a lower decrease in jump height and better consistency in jump height from one jump to the next.

Another goal of this study was to differentiate between the various evaluation formulas of the RJT and identify the most suitable one. Upon closer examination, different aspects can be captured by each individual formula. To account for potential difficulties in initiating the Repeated Jump Protocol, only Jumps 3–12 were included in Formulas F1, F5, and F8, as a strong decline in jump height during the first two RJs was not anticipated. The formulas that include Jumps 2–11 (F2, F4, F7) aim to minimize the impact of an exceptionally good first jump or a poor last jump. Nonetheless, using all jumps in the formulas should provide insight into the athletes' actual performance, with the total jump height representing the sum of these jumps. This can then be compared to an “optimal performance”.

The ideal jump height was divided into three different values: the highest single jump (F1–F2), the highest jump during the entire RJT (MaxJ; F3–F5), and the highest jump only during the repeated jumps (MaxRJ; F6–F8). Formulas F1–F5 are quite similar, as the MaxJ value often corresponds to the value of the single jump, so these formulas can be considered as representing one aspect. Thus, Formulas F1–F5 describe the difference between the optimal and actual performance, showing how close the athletes perform to their best possible performance.

Formulas that include MaxRJ (F6–F8) represent a second characteristic, potentially reflecting fatigue induced by the loaded jumps. However, this may not be solely attributed to fatigue, as some athletes reached their highest jump not in the first few jumps of the RJT but later on.

Based on our results, it is not possible to recommend only one formula. It is reasonable to consider both criteria in order to draw different conclusions about an athlete’s performance. Glaister et al. (2008)

pointed out that the most valid and suitable formula is the one that includes all sprints and the fastest sprint time multiplied by the number of sprints. In our study, this corresponds to Formulas F3 and F6. Other authors, such as Natera et al. (2023), suggest that eliminating the first and last repetition provides the most reliable measure. In our study, this applies to Formulas F2, F4, and F7.

In summary, a single formula may not be sufficient to fully represent the different characteristics of performance. To assess the discrepancy between actual and best possible performance, a formula from F1–F5 should be used. For examining potential fatigue, a formula from F6–F8 should be considered. Since only F8 showed significant differences in this second characteristic, we recommend using this formula to assess fatigue. It is more challenging to select a single formula for the first characteristic. Our results show that all formulas from F1–F5 differentiate between the sports groups. Additionally, using Jumps 3–12 reflects a more accurate trampoline routine, as the first two jumps can simulate the ascending jumps before the routine starts. Therefore, F5 is recommended for assessing the first characteristic.

It is also worth noting that TR and athletes in higher squads exhibit a lower performance decrement compared to those in lower squads across all formulas, highlighting the robustness of the test. Moreover, our RJT for TR can distinguish between groups and identify elite TR, regardless of the evaluation formula used. In summary, the study's findings align with theoretical expectations. While elite TR do not show the highest jump heights, they are more consistent and superior in trampoline-specific parameters such as performance decrement (PD) and jump-to-jump fluctuations. The most successful TR athletes also show the least PD in this test, supporting the validity of RJT. Additionally, TR demonstrated significantly lower PD in six out of eight formulas.

As a reliability analysis, we conducted correlation analyses between two separate measurements taken one week apart. Since it was only possible to measure PE twice, the reliability analysis was conducted only with this non-elite group. Pearson’s correlation is a common method for measuring test–retest reliability (Di Mascio et al., 2015; Temfemo et al., 2011). Considering only the mean jump height in the RJT, strong reliability was observed between the two separate measurements. However, when comparing the PD formulas, reliability varied from poor to moderate. For jump-to-jump fluctuations, a moderate correlation between Measurements 1 and 2 was found. Similarly high reliabilities in absolute values (MeanRJ) have also been reported in other studies (Temfemo et al., 2011). Since only the PE performed the retest, several factors may have affected their jumping performance or PD during the RJT. As noted, the PE group had the lowest MeanRJ, as well as the highest PD and jump-to-jump fluctuations, indicating they were unable to maintain jump height at a high level. This suggests the RJT’s sport specificity, as elite TR, with generally lower PD and jump-to-jump fluctuations, might maintain their performance more consistently. However, this study did not evaluate the test–retest reliability for TR, which should be addressed in future research. We expect higher test–retest reliability in trampoline gymnasts due to their lower PD and jump-to-jump fluctuations in the RJT.

In addition, participants did not receive any information about the remaining number of jumps during the test, although it was not possible to prevent them from counting along. This is important because Billaut et al. (2011) noted a higher risk of pacing in repeated high-intensity efforts when the exact number of repetitions is known. Consequently, athletes may have adjusted their efforts to manage early fatigue. While athletes in this study were instructed to perform at their maximum with every jump, they may have conserved energy for specific jumps, which could explain why the last RJ was often higher than the previous ones. Another psychological factor could be the use of audio cues, as participants did not decide when the next jump would occur. The predetermined audio and the time intervals between jumps might have negatively affected jumping performance. For future measurements, incorporating automatic acquisition of knee angles with fixed anatomical landmarks would be useful, as this could help determine if changes in knee angles occur during the RJT. Variations in knee angles might indicate greater fluctuations in jump height during the RJT.

CONCLUSIONS

Time of Flight (ToF) is of growing importance in competitive trampolining (Dyas et al., 2021), and performing a high and consistent jump height has become increasingly crucial for TR. Therefore, the aim of this study was to develop an RJT specifically for trampolining athletes and to verify its validity and reliability. An RJT should also be easy to execute and quick to evaluate. For this purpose, TR, GS, and PE performed two loaded CMJs (with 20% of their body weight) and twelve loaded RJs. Eight different evaluation formulas were used to assess their individual PDs, differing in the number of jumps and units of actual and ideal performances. The TR exhibited the lowest PD using all formulas. TR in the higher squad also showed significantly lower jump-to-jump fluctuations compared to TR in the lower squad. Test-retest reliability, measured by PE, showed high reliability when comparing the average jump height of both measurements, as well as a moderate correlation for PD and jump-to-jump fluctuations. In conclusion, the RJT developed and investigated in this study appears to be a valid and reliable tool for measuring strength endurance in TR. A higher level of expertise in TR is reflected in this RJT by lower PD and lower jump-to-jump fluctuations.

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RELATIONSHIP OF ABSOLUTE AND RELATIVE LOWER EXTREMITIES STRENGTH AND THE EFFICIENCY OF VAULT PERFORMANCE IN GYMNASTICS

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Abstract

The aim of this research was to examine the relationship between absolute and relative lower extremity strength and the efficiency of gymnastics vault performance. Thirty healthy, physically active male students (age: 20.84 ± 0.99 years; height: 179.46 ± 5.91 cm; body weight: 73.88 ± 6.43 kg) from the Faculty of Sports and Physical Education participated in the study. Absolute lower extremity strength was assessed by measuring the maximum load lifted (in kg) during a back squat (1RM). Relative lower extremity strength was calculated by dividing the estimated 1RM back squat by the participant's body weight (1RM/BW). Two types of vaults—the squat through (ST) and the front handspring (FHS)—were used to evaluate vault performance efficiency. Three criterion variables were applied: (d1) distance from the springboard in front of the vault, (d2) distance of landing beyond the vault, (d1 - d2) the difference between d1 and d2, and (pt) overall vault performance rating. The results showed statistically significant and strong correlations between both absolute and relative lower extremity strength and the variables measuring vault performance efficiency. The strongest correlations were observed for (d1), followed by (d2), (pt), and (d1 - d2). These findings can serve as guidelines for developing both absolute and relative lower extremity strength, which may lead to improved performance in gymnastics vaults.

Keywords: *absolute strength, relative strength, vaulting, artistic gymnastics.*

INTRODUCTION

Artistic gymnastics is a highly complex sport that involves bounding, jumping, tumbling, vertical landings, and rapid acceleration and deceleration movements. These actions result in high-impact loads, high strain rates, and varied strain distribution patterns on the skeleton (Farana, Jandacka, Uchytil, Zahradnik, & Irwin, 2014). As a competitive sport, artistic gymnastics requires athletes to meet high-performance standards and is characterized by dynamism, rhythm, and spectacular displays of acrobatic beauty and expressiveness (Mariana, Octavian, Daniela, & Iliana, 2016).

The vault is one of the apparatuses used in artistic gymnastics, requiring significant physical ability and performance

(Kochanowicz et al., 2016). Vaulting demands highly developed motor skills, and practicing vaults further enhances these skills. The movement pattern in vaulting improves a gymnast's speed, agility, muscle power, competitive drive, and courage (Arkaev & Suchilin, 2004). Experts emphasize the importance of factors such as run-up speed, maximal lower limb strength, the take-off angle from the springboard, and the orientation of anatomical segments and joint angles during hand contact with the vaulting table (Čuk et al., 2007; Kochanowicz et al., 2009).

Rapid position changes during each phase of the vault require gymnasts to have excellent timing, aerial awareness, and precise coordination of all involved body parts (Atiković & Smajlović, 2011; Koperski, Kochanowicz, & Słodkowski, 2010). Regardless of the vault's structure or complexity, each vault includes the following elements: the run-up, hurdling onto the springboard, the first phase of flight, the handspring off the vault, the second phase of flight, and the landing (Ferkolj, 2010). One key factor that distinguishes a gymnast's performance is the height achieved during these maneuvers, particularly vaulting. This elevation significantly impacts the judges' scoring, as highlighted by the research of Prassas, Kwon, and Sands (2006).

Vaulting is a dynamic activity performed in both men's and women's artistic gymnastics. Success in vaulting depends on a variety of factors, some independent and others within the gymnast's control. Each vault and group of vaults has a unique time structure and can be divided into seven phases. Some vaults require a faster run, while others need a slower one. Likewise, some vaults feature a long first flight phase, while others have a shorter one. In competition, gymnasts perform the most difficult vault they can safely execute.

As shown in Figures 1 and 2, each vault in the Code of Points (CoP) is divided into seven phases: (1) the run-up, (2) the jump onto the springboard, (3) springboard support and push-off, (4) the first flight phase (1stfp), (5) support and push-off from the table, (6) the second flight phase (2ndfp), and (7) the landing (Atiković & Smajlović, 2011; Čuk & Karacsony, 2004; Ferkolj, 2010; Prassas et al., 2006).

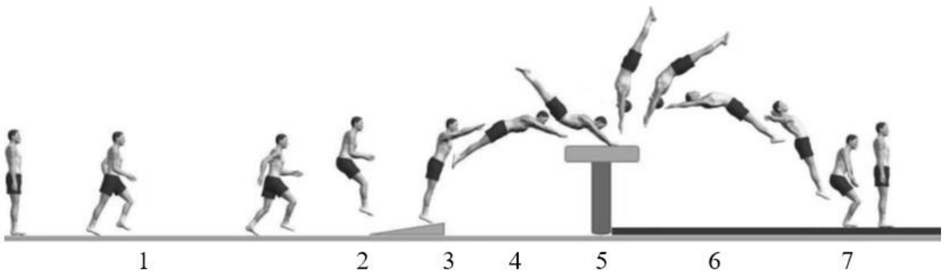

Figure 1. Vault seven phases (Atiković, 2012)

Strength is defined as a human trait, specifically the ability to overcome external resistance or oppose it through muscular effort (Nićin, 2000). The most common way to classify motor strength is by the ratio of force exerted relative to body mass. Strength can be categorized into two types: absolute strength, which is the maximum muscle strength a person can generate with their total muscle mass, and relative strength, which is the amount of strength a person can generate per kilogram of their body weight (Stojiljković, 2003).

Several authors have noted that the effectiveness of performing gymnastic exercises, including vaulting, depends not only on technical preparation but also on the gymnast's advanced psychomotor abilities and physical fitness (Zaporozhanov, Kochanowicz, & Kochanowicz, 2014). The body's vertical velocity at take-off and the net vertical impulse are key determinants of vault performance (Knudson, 2009), both of which strongly rely on segmental coordination and the application of proper technique (Bobbert, Huijing, & Schenau, 1987). A vault requires dynamic execution, achieving sufficient height and length. Gymnasts need more time to jump higher and move farther during the vault, which is associated with a higher technical level (Hashimoto, Noriyuki, & Nomura, 2017).

In their research, Atiković and Smajlović (2011) aimed to identify the biomechanical parameters that explain and define the difficulty level of a vault. Their predictor system of variables (R Square) explained 92% of the variance, while the correlation between the predictor variables and the criteria resulted in a multiple correlation coefficient of 0.96 (RO).

Schärer, Lehmann, Naundorf, Taube, and Hübner (2019) examined the relationships between run-up speed, degree of difficulty (D-score), height, and length of flight in vault performance for handsprings in artistic gymnastics. In male gymnasts, run-up velocity showed a significant correlation with the D-score, height, and length of flight, but only for Tsukahara and Yurchenko vaults. Atiković, Kazazović, Kamanješavić, and Mujanović (2019) investigated the correlation between biomechanical parameters and the vault start value in men’s artistic gymnastics. Their research aimed to determine the relationship between the vault start value and key variables such as run-up velocity, first flight phase, table support, and second flight phase. According to their correlation matrix, the criteria variables from the Code of Points FIG MAG (2017-2020) showed a statistically significant positive correlation with two variables: run-up velocity on the springboard and the second flight phase. However, there was a negative correlation with two other variables: the first flight phase and vault support.

Paunović, Veličković, Okičić, Jović, and Đorđević (2022) analyzed the relationship between physical ability factors, such as running speed, leg muscle strength, arm muscle strength, abdominal muscle strength, and balance, in vault technique. The results indicated that while these muscles do have some influence, the effect is not statistically significant. Similarly, Paunović, Veličković, Đurović, Okičić, Stojanović, and Milošević (2018) examined the impact of relative strength in various muscle groups on all-around performance. Like the previous study, the relative strength of leg muscles showed some influence on all-around results, but it was not statistically significant. In another study, Paunović, Đurović, Veličković, Živković, and Stojanović (2019) explored the effect of absolute and relative strength on floor exercise performance. Their findings mirrored those of earlier studies, showing an influence of strength, but again, it was not statistically significant.

In the research conducted by Kochanowicz et al. (2016), the authors aimed to define the correlation between maximal power of the lower limbs in youth gymnasts, kinematic analysis of the front handspring vault, and sports results. The study found a strong correlation between the results from the countermovement jump and the scores for the front handspring vault, indicating a close relationship with maximal lower limb power. Additionally, the authors identified that the most significant correlations with the judges' scores for the front handspring vault were observed in the angle of the hip joint during the second phase of flight, the moment of touching the vault surface, the height of the second flight phase, and the landing distance.

In a separate study, Bradshaw and Le Rossignol (2004) investigated vaulting talent in young female gymnasts. They found that the best regression model for predicting vaulting talent included predictor variables such as resultant velocity at take-off from the springboard, squat jump power, and average power during the last five jumps in a continuous bent-leg jump series.

Koperski et al. (2010) defined the level of quickness-force abilities in athletes and examined the correlation between take-off performance in laboratory conditions and results in actual contests. Their study found that the parameters related to muscle work in the legs and hip area were strongly correlated with springboard take-off power. Similarly, research by Qomarrullah, Kristiyanto, Sugiharto, and Hidayatullah (2018) revealed that lower extremity muscle strength had the most significant effect on performance, while running speed had the least impact.

The main purpose of this research was to determine if there are statistically significant relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency among students. We anticipate that this study will encourage further scientific exploration into the areas of lower extremity strength and gymnastics vault performance. It is hypothesized that there are statistically significant relationships between both absolute and relative lower extremity strength and gymnastics vault performance efficiency, and that it will be possible to predict vault performance efficiency based on these strength measures

METHODS

The participant sample for this study consisted of thirty male students (n=30) from the Faculty of Sports and Physical Education at the University of Sarajevo, with a mean age of 20.84 ± 0.99 years, weight of 73.88 ± 6.43 kg, and height of 179.46 ± 5.91 cm. All procedures were conducted in accordance with the Declaration of Helsinki and the ethics committee standards of the Faculty of Sports and Physical Education at the University of Sarajevo.

The research was conducted at the end of the summer semester of the academic year. Throughout the summer semester, all participants attended regular practical classes in artistic gymnastics for 15 weeks, which included vaulting exercises as part of the curriculum. During these 15 weeks, students completed a total of 45 hours of practical training, focusing not only on vaulting but also on three other apparatuses. The attendance rate for these classes was 95%. Additionally, students participated in free gymnastics practice sessions scheduled three times a week, each lasting three hours.

The assessment of absolute and relative lower extremity muscle strength, as well as the evaluation of gymnastics vault performance, was carried out in the final, 15th week of the semester. Participants were thoroughly briefed on the research program before it began.

In this research, body height and weight for each participant were measured using an InBody BSM370 stadiometer (InBody Co.).

To assess absolute and relative lower extremity strength (see Table 1), the back squat test was utilized. The back squat involves positioning a barbell across the shoulders on the trapezius, just above the posterior aspect of the deltoids. The participant then slowly flexes their hips and knees until their thighs are parallel to the floor. They then extend their hips and knees to return to the starting position, ensuring that the back remains flat, the heels stay on the floor, and the knees remain aligned over the feet (Delavier, 2010).

Table 1
Variables for assessing absolute and relative lower extremity strength.

1RM (kg) - absolute lower extremity strength
1RM/BW - relative lower extremity strength

Absolute lower extremity strength was measured as the maximum load lifted during the back squat, expressed in kilograms (1RM). Relative lower extremity strength was calculated by dividing the estimated 1RM back squat by the participant's body mass, resulting in (1RM/BW).

The protocol for assessing absolute and relative lower extremity strength was adapted from Kraemer, Fry, Ratamess, and French (1995). Participants began with a warm-up consisting of 8-10 repetitions with a light load (approximately 50% of the expected 1RM). This was followed by 3-5 repetitions with a moderate load (approximately 75% of the expected 1RM) and then 1-3 repetitions with a heavy load (approximately 90% of the expected 1RM). After warming up, participants attempted the 1RM test by progressively increasing the load until either their technique was significantly compromised or they could no longer lift a heavier weight. The load was increased by 2.5 to 5 kg with each attempt (Stone et al., 2003). A rest period of 5 minutes was observed between attempts.

To assess the efficiency of gymnastics vaults, two vaults that are part of the curriculum for the first cycle of studies at the Faculty of Sports were used. As shown in Figures 2 and 3, the success of performing the vault elements was evaluated using the following criteria: ST - squat through; FHS - front handspring vault.

The following variables were used to assess the gymnastics vaults performance efficiency (Table 2 and Figure 4).

Figure 2. ST - squat through (Atiković, Tabaković, Hmjelovjec, Kalinski, & Stoicescu, 2009).

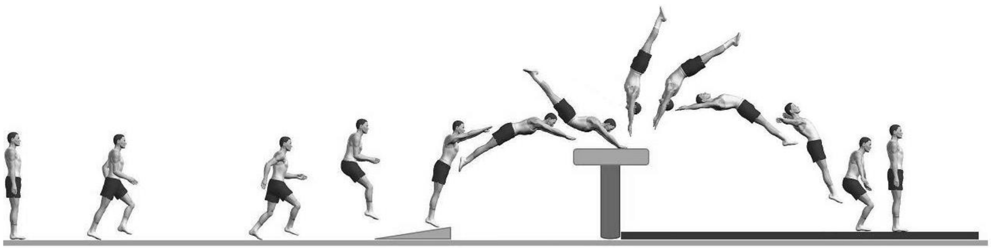

Figure 3. FHS - front handspring vault (Atiković, 2012).

Table 2
Variables for assessing the gymnastics vaults performance efficiency.

ST - squat through	d1(cm) - distance from the springboard in front of the vault d2 (cm) - distance of landing beyond the vault
FHS - front handspring vault	d1 - d2 (cm) - the difference between d1 i d2 pt (points) - overall vault performance rating

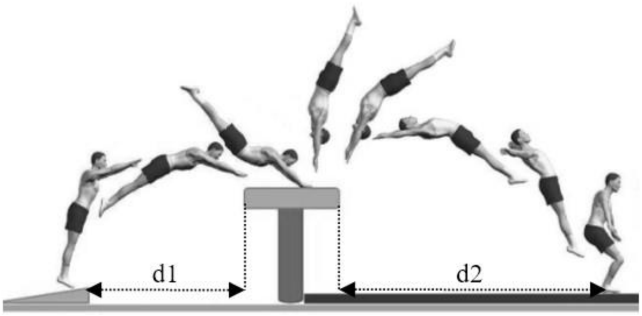

Figure 4. Characteristics of variables vaults prepared upon the Atiković (2012) scheme, being modified. All markings are approximate.

The variable (d1) is defined as the distance from the springboard take-off in front of the vault. Variable (d2) - defined as the distance of landing beyond the vault. Variable (pt) - overall vault performance rating, defined as the overall technical efficiency of the vault performance expressed in points.

At the beginning of the summer semester, participants had no prior knowledge of gymnastics vaults. By the 15th week of classes, an assessment of two gymnastics vaults, the ST (squat through) and FHS (front handspring) vaults, was conducted to evaluate performance efficiency. The final evaluation was carried out by experts (N = 4) from the University, each with over 20 years of experience working in various sports clubs and at the Faculty of Physical Education and Sports.

The assessment took place in a gym equipped with vaulting apparatuses, including a vault height of 135 cm and a maximum run-up distance of 25 m, using an "Elan" springboard for takeoff. To measure variable (d1) – the distance from the springboard to the vault – a measuring tape in centimeters was placed at the springboard location. Similarly, another measuring tape was placed on the landing mats to measure variable (d2) – the distance of landing beyond the vault. Prior to the evaluation, examiners reviewed the task descriptions and criteria outlined in Table 3. Each examiner assessed the participants independently during the exam, without communication with each other or revealing their assigned scores. The final evaluation of gymnastics vault performance efficiency was based on scores from judges (N = 3).

Table 3
Criteria for Gymnastics Vaults knowledge evaluation.

Measuring scale (points)	Description of standards - Gymnastics Vault
Points 6 or 6.5	The vault was executed with major errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Major errors may be evident in the aesthetic aspect of the vault, including the poor posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of major errors is 8 or more for a rating of 6, and 7 errors for a rating of 6.5.
Points 7 or 7.5	The vault was performed with errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. These errors may be present in the aesthetic aspect of the vault, including the poor posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of errors is 6 for a rating of 7, and 5 errors for a rating of 7.5.
Points 8 or 8.5	The vault was executed with minor errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Possible minor errors may be found in the aesthetic aspect of the vault, including slight deviations in the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of errors is 4 for a rating of 8, and 3 errors for a rating of 8.5.
Points 9 or 9.5	The vault was performed with minor errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Possible minor errors may be present in the aesthetic aspect of the vault, including slight deviations in the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of minor errors is 2 for a rating of 9, and 1 error for a rating of 9.5.
Points 10	The vault was executed optimally without errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. There are no errors in the aesthetic aspect of the vault, including the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and the landing is secure.

The level of agreement among judges was assessed using Cohen's Kappa coefficient. The reliability coefficient among judges was .72, indicating a high level of agreement. However, upon reviewing individual agreement coefficients, it was found that one judge had a lower agreement coefficient compared to the other three judges. Consequently, the ratings from this judge were excluded from the final processing of the results.

The subjects performed both gymnastics vaults, the (ST) - squat through and (FHS) - front handspring, twice (see Table 2 and Figures 2, 3, 4). Only the better performance of each vault was used in the analysis. All thirty participants executed the vaults independently, without physical assistance. Students who could not perform the vault independently did not participate in the study. Judges recorded the following on the participant's card: (d1) - the distance from the springboard to the vault in centimeters, (d2) - the distance of landing beyond the vault in centimeters, and (pt) - the overall vault performance rating in points. Subsequently, the difference between (d1 - d2) was calculated in centimeters. The final evaluation for variable (pt) - overall vault performance rating was made using a scale from 6 to 10 points (see Table 3), according to the modified criteria by Tabaković, Tabaković, and Atiković (2023), where 10 points represented the highest rating. To better differentiate vault performances, judges could assign scores with half-point increments (e.g., 6.5; 8.5). The same procedure was followed by seven teachers, experts in the field of gymnastics, to set the criteria for optimal performance of a "handspring" vault (Milosis, Siatras, Proios, Proios, Christoulas, & Papaioannou, 2018). After evaluating the better performances, the final grade for each examinee for each task was calculated as the arithmetic mean of the scores assigned by the examiners

The Statistical Package for the Social Sciences (SPSS), version 21.0 (SPSS Inc., Chicago, Illinois), was used for data processing. Descriptive statistics (mean value and standard deviation) were calculated for all variables. To determine the relationships between absolute and relative lower extremity strength and vault performance efficiency, Pearson's correlation coefficient (r) was applied. Regression analysis was employed to establish the prediction of vault performance efficiency based on absolute and relative lower extremity strength. For this purpose, the following were calculated: β - standardized values of the regression coefficient; t - standardized tests of the significance of the regression coefficient; p - the level of significance of the standardized regression coefficient; R - multiple regression; R^2 - coefficient of determination; R^2_adjusted - adjusted coefficient of determination; F - significance test of multiple regression analysis; and p - significance level of multiple correlation. The Shapiro-Wilk test was used to check the normality of the distribution.

RESULTS

The results of arithmetic means, standard deviations, and Pearson's correlation coefficients for absolute and relative lower extremity strength variables and variables measuring vault performance efficiency are presented in Table 4. For the variables assessing gymnastics vault performance efficiency, slightly higher mean values were obtained for the variable (d1) - distance from the springboard in front of the vault compared to variable (d2) - distance of landing beyond the vault. The normality of the distribution of results was confirmed by the Shapiro-Wilk and Kolmogorov-Smirnov tests, which yielded values greater than .05 for all applied variables.

Upon examining Pearson's correlation coefficient, statistically significant and high correlation values were observed at the significance levels (p = .01 and .05) between absolute and relative lower extremity strength variables and variables measuring gymnastics vault performance efficiency. The highest correlations were found with variable (d1) - distance from the springboard in front of the vault, followed by variables (d2) - distance of landing beyond the vault, and variable (pt) - overall vault performance rating.

The results of the regression analysis for gymnastic vaults (ST) - Squat Through and (FHS) - Front Handspring Vault are presented in Table 5. The predictor system of variables (1RM) - absolute lower extremity strength and (1RM/BW) - relative lower extremity strength, coefficient of determination explains the shared variability with the criterion variables in the range of (R^2 = 67%) to (R^2 = 45%), with a level of statistical significance (p = .00). The criterion variable (d1) - distance from the springboard in front of the vault had the highest shared variability with the predictor variables, followed by (d2) - distance of landing beyond the vault and (pt) - overall vault performance rating, but there was no statistically significant variability with the variable (d1 - d2) - the difference between d1 and d2. The values of adjusted coefficient of determination R^2_{adjust} ranged from (R^2_{adjust} = .64) to (R^2_{adjust} = .14). The values of multiple correlation coefficients R, which have levels of statistical significance at (p = .00), ranged in values from (R = .82) to (R = .68), representing a high value. Upon analysis of partial regression coefficients, β values, which have levels of statistical significance at (p = .00 and p = .01), it was observed that the predictor variable (1RM) - absolute lower extremity strength has statistically significant correlations with all criterion variables except for one correlation (d1 - d2) - the difference between d1 and d2. The correlation values range from (β = .68) to (β = .57). The predictor variable (1RM/BW) - relative lower extremity strength does not have statistically significant correlations with the criterion variables for vaults

Table 4
Arithmetic means, standard deviations, and Pearson's correlation coefficients of variables absolute and relative lower extremity strength and variables measuring the vaults performance efficiency

Variable	M ± SD		
1RM (kg)	89.67 ± 13.70		
1RM/BW	1.21 ± .19		
ST - squat through Variable	M ± SD	1RM r	1RM/BW r
d1(cm)	109.93 ± 12.36	.81**	.71**
d2 (cm)	101.33 ± 11.68	.74**	.68**
d1 - d2 (cm)	8.60 ± 3.16	.43*	.29
pt (points)	7.68 ± .70	.73**	.66**
FHS - front handspring vault Variable	M ± SD	1RM r	1RM/BW r
d1 (cm)	107.53 ± 13.24	.77**	.69**
d2 (cm)	97.77 ±11.23	.75**	.67**
d1 - d2 (cm)	9.77 ± 4.11	.40*	.35
pt (points)	7.28 ± .78	.67**	.61**

Data are presented as the M ± SD. r- Pearson's correlation. p- significance level of Pearson's correlation. **. The mean difference is significant at the .01 level. *. The mean difference is significant at the .05 level

Table 5
Regression analysis of vault ST - squat through and FHS - front handspring

Criterion Variables	Predictor Variables	β	t	p	R	R^2	R^2_{adjust}	F	p
d1 (cm)	1RM (kg) 1RM/BW	.68 .17	3.58 .88	.00 .39	.82	.67	.64	27.10	.00
d2 (cm)	1RM(kg) 1RM/BW	.56 .22	2.60 1.03	.01 .31	.75	.57	.53	17.66	.00
d1 - d2 (cm)	1RM(kg) 1RM/BW	.36 .17	1.23 .58	.22 .57	.41	.22	.14	3.29	.07
pt (points)	1RM(kg) 1RM/BW	.64 .04	2.63 .15	.01 .88	.72	.45	.41	11.07	.00
d1 (cm)	1RM (kg) 1RM/BW	.59 .21	2.79 1.01	.01 .32	.78	.59	.56	19.36	.00
d2 (cm)	1RM(kg) 1RM/BW	.57 .22	2.67 1.02	.01 .32	.74	.57	.54	18.20	.00
d1 - d2 (cm)	1RM(kg) 1RM/BW	.33 .09	1.09 .30	.28 .77	.40	.20	.16	2.63	.09
pt (points)	1RM(kg) 1RM/BW	.65 .15	2.99 .69	.01 .50	.68	.58	.55	16.44	.00

Data are presented as the β - Standardized values of the regression coefficient. t- Standardized tests of the significance of the regression coefficient. p - The level of significance of the standardized regression coefficient. R - Multiple correlation coefficients. R^2 - Coefficient of determination. R^2_{adjust} - Adjusted coefficient of determination. F - Significance test of multiple regression analysis. p - Significance level of multiple correlation

DISCUSSION

This research aimed to determine the relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency. The authors also sought to explore the possibility of predicting gymnastics vault performance efficiency based on absolute and relative lower extremity strength. The main finding of this research is that statistically significant relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency were observed in almost all variables. Based on the values of multiple correlations and partial regression coefficients, it is possible to successfully predict gymnastics vault performance efficiency using absolute and relative lower extremity strength.

The analysis of the arithmetic means, Pearson’s correlation coefficients, and regression analysis of variables measuring absolute and relative lower extremity strength, along with those assessing vault performance efficiency, yields the following discussion of results. The mean values for gymnastics vaults are slightly higher for the squat through vault compared to the front handspring vault, as expected, given the simpler motor structure of the squat through vault. Statistically significant and strong Pearson’s correlation values were obtained between absolute and relative lower extremity strength variables and vault performance efficiency. Regression analysis also revealed statistically significant and strong multiple correlations and partial regression coefficients, demonstrating a positive and significant influence of absolute and relative lower extremity strength on vault performance efficiency, as well as the potential to predict vault performance efficiency based on these strength measures.

The predictor variable (1RM) – absolute lower extremity strength – proved more effective in predicting vault performance efficiency based on partial regression coefficients. The highest values for the arithmetic means, Pearson’s correlation coefficients, and regression coefficients were found in the following criterion variables: (d1) – distance from the springboard in front of the vault, (d2) – landing distance beyond the vault, (pt) – overall vault performance rating, and (d1 - d2) – the difference between d1 and d2.

Based on these results, it can be concluded that participants performed vaults with a slightly greater distance from the springboard compared to the distance they achieved during the landing phase. This led to slightly lower final scores for overall vault execution. One possible reason for this performance outcome is that the college students had limited prior experience performing vaults, whereas elite gymnasts typically achieve a shorter difference between the takeoff and landing phases.

A small number of studies similar to this one exist. The following studies are presented as partial support for this research. Only the results and discussions from studies that partially confirm the findings of our study have been extracted.

Atiković and Smajlović (2011) found a statistically significant correlation between criterion variables from the COP matrix (FIG, 2009) and five variables: BCG velocity on the springboard ($r = 0.768$, $p < 0.05$), alpha in the x-axis during the second flight phase ($r = 0.759$, $p < 0.05$), and time of the first flight phase ($r = -0.486$, $p < 0.01$). Their analysis of the impact of individual variables showed the greatest and most statistically significant influence of criterion variables from the COP matrix on the following individual variables: alpha x during the second flight phase ($\beta = 0.835$, $p < 0.001$), alpha y during the second flight phase ($\beta = 0.375$, $p < 0.001$), and moment of inertia Jx in the second flight phase ($\beta = 0.373$; $p < 0.001$).

Farana and Vaverka (2012) reported that five out of 23 examined variables showed significant correlations with the scores. Significant correlations were found in the vertical height of the body mass center during take-off from the vaulting table ($r = 0.86$), the maximum height of the body mass center in the second flight phase ($r = 0.83$), the horizontal velocity change during the take-off phase from the vaulting table ($r = -0.69$), the horizontal velocity component during take-off from the vaulting table ($r = 0.75$), and the duration of the second flight phase ($r = 0.69$).

The significance of the research by Paunović et al. (2022) lies in determining the influence of absolute and relative muscle strength in the legs, upper arms, and shoulder girdle on the success of vault performance. While the influence of relative strength compared to absolute strength is greater, it does not reach statistical significance. Based on the results, it can be concluded that neither absolute nor relative strength is a decisive factor for vault success. Specifically, the muscles of the shoulder girdle have the greatest influence on vault performance, although this influence is not statistically significant. The beta coefficient values indicate a very small influence from the upper arm muscles (-.144) and a small influence from the leg muscles (-.322), while the shoulder girdle muscles have a larger influence, contributing 52.5% ($\beta = .525$).

In Paunović et al. (2018), the authors examined the influence of the relative strength of different muscle groups on the all-around performance of gymnasts aged 14 to 16. While relative strength of the leg muscles influences all-around results, this influence is not statistically significant ($p = 0.413$). Similarly, the influence of the upper arm muscles was not significant ($p = 0.926$). As in the previous study, the shoulder girdle muscles had the greatest influence ($\beta = 0.499$), though still not statistically significant ($p = 0.653$). The results for this set of variables closely mirror those from the earlier study.

In another study, Paunović et al. (2019) examined the influence of absolute and relative strength on the success of performing the floor exercise. Using a sample of respondents aged 14 to 16 years, the results were similar to those of previous studies. While both absolute and relative strength showed influence, it was not statistically significant. For absolute strength, the significance level was (p =

0.295), and for relative strength, it was ($p = 0.284$).

Čuk and Karacsony (2004) presented the biomechanical characteristics of vaulting, identifying the most important factors for successful vaulting, such as morphological characteristics, run velocity, length of flight on the springboard, duration of board contact, foot position relative to the springboard edge, duration of the first flight phase, duration of table support phase, duration of the second flight phase, jump height, moments of inertia on the x and y axes, distance during the second flight phase, and landing.

A gymnastics vault clearly reflects the specificity of effort, which is influenced by various manifestations of dynamic strength. This strength is primarily evident during the take-off from the springboard through the lower extremities, and during the take-off from the apparatus through the upper extremities. Static strength, which opposes dynamic strength, is demonstrated during landing (Kochanowicz et al., 2009).

According to research conducted by Marinšek (2010), the physical preparation and motor control of gymnasts are determining factors for all phases of vault exercises in artistic gymnastics, including the run-up, jump onto the springboard, springboard support phase, first flight phase, and landing.

In the study conducted by Koperski et al. (2010), the highest and most statistically significant correlation between gymnasts' results in take-off power, assessed on a tensiometric platform and the springboard, was ($r = 0.916$) at ($p \leq 0.05$). Additionally, a crucial correlation was observed between the time of the contestant's contact with the ground during laboratory tests and the same parameter measured during take-off from the springboard ($r = 0.668$). The analysis of test results reveals a strong correlation between athletes' speed and force abilities in laboratory conditions and the physical values exhibited during springboard take-off in actual competition. Therefore, the measurement of speed-force abilities (take-off power) in laboratory conditions can be an effective measure of athletes' preparedness for gymnastic vaults.

Previous research by Kochanowicz and Kochanowicz (2014) demonstrated that vault performance effectiveness is influenced by somatic features, motor abilities, and technical skills. In a later study by Kochanowicz et al. (2016), mean values of lower limb power indicators and their correlation with the vault score were as follows: maximal power (W) 1400.91 ± 502.74, ($r = 0.401$*); relative maximal force (%BW) 234.87 ± 34.34, ($r = 0.330$*). Additionally, mean values of biomechanical indicators and their correlation with the score for the front handspring vault were: d0 (springboard distance before the vault) 96.64 ± 22.78 cm, ($r = 0.441$*), and d3 (landing distance) 138.73 ± 45.79 cm, ($r = 0.631$**).

Testing of the second hypothesis on the influence of leg muscle strength on vault technique yielded a significant result ($r = 0.000$, $p < 0.01$). The influence ($\lambda = X^2 \rightarrow Y$) belongs to the medium category, with the most significant impact on the correlation value of 0.454. The movement of the lower extremities during the run-up to the round-off position and the landing point at the fulcrum is driven by leg muscle strength. Leg muscle strength contributes to the power of foot jumps, while maximal explosive muscle strength enhances acceleration capabilities (Qomarrullah et al., 2018).

Several factors contributed to the relationships identified between absolute and relative lower extremity strength and gymnastics vault performance efficiency in this research, including the participant sample. The participants were students who had no significant prior knowledge of gymnastics vaults. After 15 weeks of regular gymnastics classes, the students gained knowledge of vaulting, which correlated significantly with their absolute and relative lower extremity strength.

Another contributing factor was the selection of variables. Different results might have been observed if the study had included additional variables to assess muscle strength in the arms, shoulder girdle, or other motor abilities influencing vaulting efficiency. A third factor was the inclusion of both the squat through and front handspring vaults, as well as the criterion variables used to evaluate vaulting efficiency. Although not highly complex in movement structure, both vaults are challenging for students, with those displaying higher levels of absolute and relative lower extremity strength achieving more successful performances.

Absolute and relative lower extremity strength had the greatest impact on the criterion variables for vaulting: (d1) - the distance from the springboard ahead of the vault, followed by (d2) - the distance of landing behind the vault, and (pt) - overall vault performance rating.

From the foregoing, this research has some limitations in terms of theoretical and practical usefulness. These limitations are reflected in the fact that the results of our study can primarily be applied to students at sports faculties and beginners in artistic gymnastics and, therefore, cannot be generalized or applied to elite gymnasts. Additionally, one of the limitations is that, aside from absolute and relative strength, other factors crucial for vaulting efficiency, as mentioned earlier, were not addressed in this study.

CONCLUSION

This study investigated the relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency. Significant statistical relationships between absolute and relative lower extremity strength and vaulting efficiency were found in almost all variables examined. The prediction of vaulting efficiency based on these strength measures can be successfully determined using multiple correlations and partial regression coefficients.

We hope this study stimulates future scientific research on the role of lower extremity strength in gymnastics vaulting. The value of this research lies in its potential to highlight the importance of enhancing absolute and relative lower extremity strength in sports gymnastics classes at sports faculties, making it easier for students and individuals without prior vaulting experience to learn and improve their vaulting performance. Future studies could investigate gymnasts performing more complex vaults, incorporating a wider range of strength-related variables and a more comprehensive set of vaulting efficiency measures

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KINEMATIC CHARACTERISTICS OF THE APPROACH RUN ON HANDSPRING VAULT BY HIGH LEVEL MALE GYMNASTS

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Abstract

The approach run is a fundamental precondition for successful vault performance, as it enables the gymnast to develop maximum controlled horizontal velocity. The purpose of this study was to investigate the length, frequency, and velocity of steps during the run-up phase (approach run) in the execution of the handspring vault on the vaulting table. Nine high-level male artistic gymnasts, who performed the handspring vault under training conditions, volunteered to participate in the study. Five video cameras—four stationary and one scanning—were used to record the run-up phase, the hurdle step, and the take-off from the springboard. The gymnasts performed six trials of the handspring vault with a three-minute rest between each trial. Results showed that the final step was shorter than the penultimate step, and the penultimate step was longer than the preceding step. Additionally, the gymnasts demonstrated a gradual increase in their run-up velocity, a key requirement for a successful jump, up to the penultimate step. The average step frequency among gymnasts ranged from 3.20 to 4.88 steps per second, while the average step velocity across the six attempts was between 4.03 and 7.37 m/sec. Finally, a gradual increase in the gymnast's velocity was observed up until the last step, with the final step being shorter than the penultimate step and the penultimate step being longer than the one before it.

Keywords: *Kinematic characteristics, step length, approach run, hurdle step, handspring vault.*

INTRODUCTION

Vaulting in artistic gymnastics (AG), is the only event that consists of a single exercise, and due to the complexity of the movements involved is the most researched and best understood apparatus (Prassas et al., 2006). Vaulting is one of the events of AG that characterized by very short duration lasting up to five to six seconds (Čuk & Karacsony, 2004) and consisted by seven phases; (i) run-up, (ii) hurdle step, (iii) take-off form board, (iv) 1st flight phase, (v) push-off, (vi) 2nd flight phase, and (vii) landing (Takei, 2007). The approach run is one of the basic preconditions for successful performance on the vault as it enables the gymnast to developed the maximum possible controlled horizontal velocity which facilitates proper execution of the next phases (Veličković et al., 2011). Running velocity, is one of the most crucial elements for a good vault, as listed by previous authors (Atiković & Smajlović, 2011; Cuk & Karacsony, 2004). Previous findings by Čuk et al. (2007) who investigated the relationship between the difficulty values (DV) of vault and runway velocity in top level male artistic gymnasts revealed that the correlation between each gymnast's runway velocity and DV of the vault was much lower than the correlation between average velocity of the jump and its DV. Furthermore, the study by Atiković (2012) who investigated the relation between vault difficulty value and biomechanical parameters in men's AG, revealed that the best model only predicted the second flying phase with 95% of the variation explained. Furthermore, the approach run is not performed just to develop the gymnasts the maximum possible velocity but involves complicated motor control as gymnasts must balance the velocity requirements with an accurate take-off (Bradshaw, 2004). Thus, the goal of the gymnasts to achieve the maximum controlled take-off angle and take-off velocity during the last stride, hurdle step, relies on maximizing step velocity (SV) during the approach run phase. Increasing approach velocity has resulted in higher velocity at springboard take-off, an increase in temporal parameters in 1st and 2nd flight phases, and a decrease in springboard and vault contact times which permit greater number of body rotations during second flight phase (Farana et al., 2013). During take-off from the springboard and vaulting table, the horizontal kinetic energy that was gathered during the run-up, is converted into angular and vertical kinetic energy to facilitate an optimal second flight phase (Prassas et al, 2006). The development of the necessary propulsion on the springboard in order to gain enough height and distance for hand-placement on the vaulting table is heavily dependent on the velocity achieved at the last step of the approach and the resultant take-off velocity and angle prior to landing on the springboard (i.e. the hurdle step). Further, increasing post-flight time provides gymnasts with the ability to complete more complex acrobatic movements, increasing the degree of difficulty and the potential for a higher score (Bradshaw, Hume, Calton & Aisbett, 2010).

The technique of performing the approach run in vaulting, particularly during the final two steps and the hurdle, differs significantly from running in simpler conditions where a hurdle step is not required after the last stride (Meeuwsen and Magill, 1987). Considering that the hurdle step must be executed from a precise distance, which is largely dependent on the velocity achieved during the last stride, the primary objective for gymnasts is to maximize step velocity (SV). This is accomplished by increasing both step frequency (SF) and step length (SL), the two components that constitute SV (Hunter et al., 2004), although these components are inherently different.

However, SF and SL during sprint running exhibit a negative interaction due to the conflicting demands associated with increasing each (Hunter et al., 2004; Salo et al., 2011). The importance of approach velocity is underscored by Tashiro et al. (2008), who highlight its significant contribution to the successful execution of the vault. Numerous studies have also emphasized the positive correlation between run-up velocity and gymnastic scores (Sands & McNeal, 1995; Takei, 1988; Takei et al., 1996). According to Sands (2000), the run-up phase is considered one of the predictors of a successful vault, with maximum running velocity and the number of steps being crucial elements in this prediction.

The initial increase in velocity, up to sub-maximum levels of around 6 m/s, is primarily due to an increase in SL (Thorstensson & Robertson, 1987). Following this, further increases in velocity are largely attributed to an increase in SF (Kuitunen et al., 2002; Mero & Comi, 1985; Weyand et al., 2000).

When performing the approach run, gymnasts progressively increase their velocity as they near the springboard, aiming to achieve maximum possible speed during the take-off phase. This increase in velocity enables experienced gymnasts to execute better rotations around the body axes, thanks to greater speed and push, allowing them to perform vaults efficiently even at very high speeds (Penitente et al., 2007). As Bradshaw (2004) noted, the run-up phase during vaulting can be divided into two distinct phases: (a) an accelerative phase, where the gymnast builds velocity, and (b) a visually controlled (targeting) phase, where, once near top velocity, gymnasts use their vision to regulate their step pattern, ensuring they 'hit' the springboard in the optimal position for take-off. According to the existing literature, this study is the first to examine the entire run-up phase on the vaulting table with high-level gymnasts performing the handspring vault.

METHODS

The sample consisted of nine high level male artistic gymnasts (mean age 23.33 ± 5.22 years; body mass: 62.89 ± 6.47 kg; height: 169.22 ± 06.51 cm) that were voluntarily participated in this study. They were members of national team with average training experience 19.00 ± 5.45 years and participating in international competitions. After being informed of the purpose of the study, it was clarified that they have the right to leave at any time during the experimental process if they so wished. Approval for the investigation was obtained from the School of Physical Education and Sport Science's, of the National and Kapodistrian University's ethics committee (1350/03-03-2022). Written informed consent was obtained from the participants. The study was conducted in accordance with the Declaration of Helsinki for human experimentation.

The experimental task involved the run-up phase (approach run) for executing a handspring on the vaulting table, with each gymnast using their full individual approach run. A personalized warm-up, similar to what they typically perform before a competition, preceded each set of handspring vaults. The approach run distance was measured from the leading edge of the vaulting table, and the springboard was positioned according to the gymnasts' self-selected springboard-to-vaulting table distance. Gymnasts were instructed to perform each vault with maximum effort. A six-minute passive rest period was observed between each trial.

Prior to testing, a familiarization session was conducted where all gymnasts performed three handspring vaults, with 3-minute recovery periods between each vault. This session allowed for the accurate determination of (a) the length of their approach run, (b) the springboard-to-vaulting table distance (BTD), and (c) the distance between the last support phase of the approach run (take-off to hurdle step) and the springboard. Two days after the familiarization procedure, the gymnasts returned to the gymnasium to perform six handspring vaults.

According to the guidelines of the International Gymnastics Federation (F.I.G., 2022), the vaulting event consists of an approach runway, a springboard, and a vaulting table set at a height of 1.35 m. The 25-m long and 1-m wide runway is marked with custom black-and-white markers placed at 1 m intervals along its length, parallel to the boundaries' long axis. White tape strips were also placed at the four edges of the springboard for added precision.

The approach phase towards the vault table was recorded using one panning and four stationary high-speed video cameras (Casio Computer Co. Ltd, Exilim-Pro-EX-F1, Shibuya, Japan) at a sampling rate of 300 fps (resolution: 512 × 384 pixels). The position of each camera, along with the overall process of recording and analyzing the kinematic characteristics of the approach run, followed procedures outlined in a previous study (Dallas & Theodorou, 2020).

Twenty-two anatomical points (including the tip of the toe, 5th metatarsal, heel, ankle, knee, hip, shoulder, elbow, wrist, and 5th metacarpal on both sides of the body, the 7th cervical vertebra, and the top of the head) were marked with spherical markers of 0.02 m in diameter. These markers were attached to the skin using black double-sided adhesive tape to create a white-on-black contrast. The collected videos were digitized using kinematic analysis software (Ariel Dynamics Inc., APAS v13.3.0.3, Trabuco Canyon, CA, USA), and the coordinates of the body's center of mass (CoM) were calculated for every frame based on the anatomical data provided by Plagenhoef (1985).

A second-order low-pass Butterworth filter with a cut-off frequency of 6 Hz was applied for smoothing the data. The accuracy of the 2D reconstruction was determined by the root mean square error (RMSE), calculated after randomly re-digitizing 10% of the captured frames. An error of 0.45 cm and 0.63 cm was found for the X (horizontal) and Y (vertical) axes, respectively.

Toe–table distances (TTDs) for each foot placement during the gymnasts' approach run were measured using a 5-point model. This model included the toe-off point during the support phase (contact) of the gymnast's foot on the ground and the four markers surrounding the foot at ground contact (Hay & Koh, 1988). The support phase refers to every instance of the gymnast's foot contacting the ground while running on the runway, hurdling, or stepping on the springboard. The horizontal distance between the toe and the line formed by the two closest digitized markers (toe–marker distance) was obtained. TTD was then calculated by adding the toe–marker distance to the marker–table distance.

The validity of this procedure for calculating the TTD was assessed by recording test panning and stationary videos from each respective camera, with a gymnast placing his foot on the runway at known distances (0.10 m, 1 m, 2 m, 3 m, and every 2 m thereafter up to 25 m from the front edge of the vaulting table) (Berg & Mark, 2005; Bradshaw, 2004). The TTD of the 'calibration feet' was then calculated using the aforementioned method. The comparison between the actual TTD and the TTD derived from video analysis revealed a mean absolute error of 0.01 m in the measured distances.

The accuracy of the kinematic analysis was further determined through intra-researcher reliability. For this purpose, 10% of the recorded frames were re-digitized, and the same data analysis was conducted. The intraclass correlation coefficient (ICC) was found to be 0.998 (95% confidence interval: 0.997–0.999).

A step was defined as the distance between two consecutive foot touchdowns (support phases), and its length was calculated by subtracting the consecutive TTDs. TTDs and step lengths were calculated for all support phases and steps, respectively, of each gymnast's approach run. The distance from the toe to the leading edge of the springboard at the moment of landing on the springboard was identified as the toe–board distance (TBD).

Based on the XY coordinates extracted from the digitized anatomical points, the following kinematic (dependent) variables (DV) were calculated for the approach run: (a) step length [cm], (b) step frequency [steps/sec], (c) horizontal velocity [m/sec], and (d) length of the hurdle step [m]. The duration (contact time) of the support phase during the hurdle step (TClast) and on the springboard (TCsb) was defined as the time elapsed (in seconds) from the initial contact to the final contact of the foot with the ground or springboard, respectively. Descriptive statistics were employed to calculate the aforementioned DVs during the performance of the approach run.

All statistical analyses were conducted using SPSS software (SPSS v. 28, IBM Corp., NY). In the initial stage of data processing, kinematic characteristics (length, frequency, and speed) were recorded for all six attempts of each athlete. Descriptive statistics were then employed to compute the means and standard deviations of the dependent variables across each athlete's six attempts. Subsequently, an analysis of variance with repeated measures was performed to assess differences between individual running steps.

RESULTS

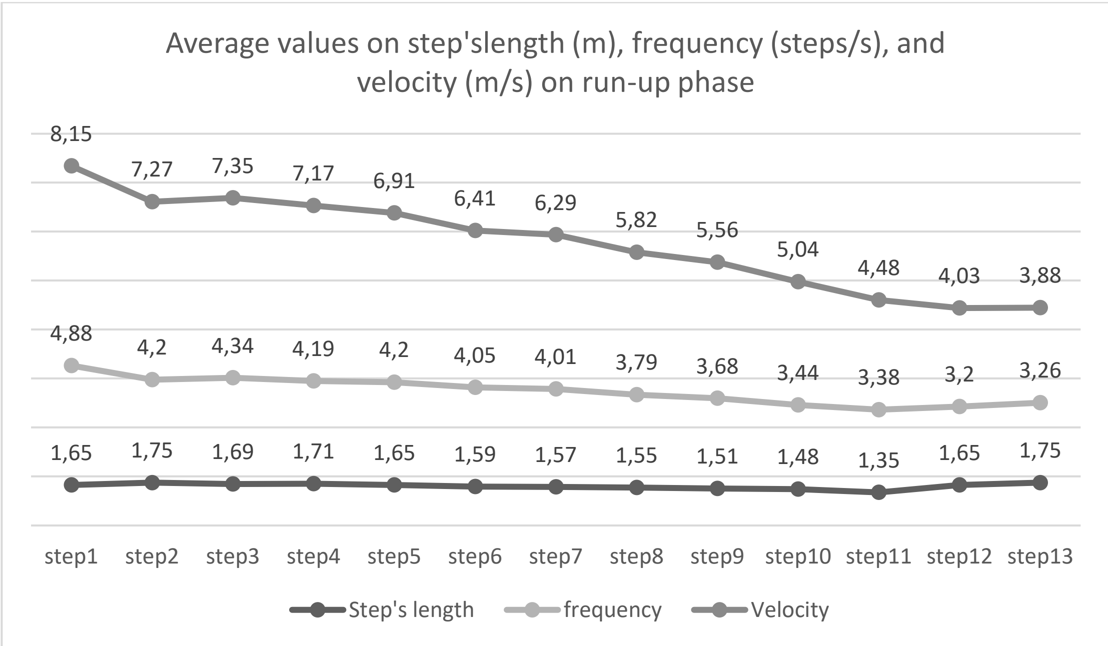
Kinematic analysis showed that the mean step length across the six attempts was 156.31 ± 8.78 cm. Detailed values for each gymnast are presented in Table 1.

Furthermore, the average step frequency across 6 attempts was 3.85 ± 0.31 steps per second. Detailed values for each gymnast are presented in Table 2.

Kinematic analysis showed that the average step velocity of the gymnasts during the entire approach run was 6.03 ± 1.36 m/sec. Detailed values for each gymnast are presented in Table 3.

However, the run-up phase of the gymnasts is characterized by a continuous increase in horizontal velocity and step frequency, while step length generally increases. Notably, the penultimate stride is on average 10 cm shorter than the final stride (see Graph 1).

The repeated measures analysis revealed a statistically significant difference in running steps between individual strides ($F = 16.520$, $p < .001$). Significant differences were noted in the 2nd, 3rd, 4th, 5th, 7th, and 8th strides.



Graph 1. Characteristics of the run up phase

Table 1. *Data on the average step length for each gymnast across 6 attempts on handspring vault.*

Step	G1	G2	G3	G4	G5	G6	G7	G8	G9	x ± sd
HS	294	310	280	276	311	294	314	312	316	300.78±15.24
LS	175	182	167	150	155	163	174	161	160	165.22±10.26
S2	165	178	184	156	175	194	192	171	160	175.00±13.42
S3	169	179	167	156	174	171	181	166	161	169.33±8.04
S4	163	186	171	158	181	174	187	163	158	170.89±11.03
S5	158	168	173	161	169	163	168	163	160	164.78±4.94
S6	147	170	170	152	176	175	145	149	149	159.22±13.11
S7	144	161	165	163	166	155	159	144	155	156.89±8.26
S8	140	159	161	169	168	160	145	143	154	155.89±10.00
S9	138	148	146	160	169	170	140	140	149	151.11±12.32
S10	138	153	145	168	162	157	137	136	134	147.78±12.60
S11	123	137	148	141	145	128	125	136		135.37±9.27
S12	119	109	137	138	115	125	130			124.71±11.02
S13	107		144		113	112				119.00±16.87
X	145.07	160.83	159.84	156.00	159.07	157.46	156.91	152.00	154.00	159.22±11.56

G: Gymnast; HS: Hurdle step; LS: Last step; S: Step; x: mean value; sd: standard deviation

Table 2. *Data on the average step frequency (s* $^{-1}$*) (step/sec) for each gymnast across 6 attempts on handspring vault.*

Step	G1	G2	G3	G4	G5	G6	G7	G8	G9	x ± sd
LS	5.00	4.82	4.10	5.46	5.00	5.14	4.76	4.80	4.89	4.88 ± 0.36
S2	4.27	4.11	4.22	4.60	3.93	4.14	3.92	4.13	4.52	4.20 ± 0.23
S3	4.32	4.15	4.04	4.72	4.12	4.59	4.24	4.18	4.73	4.34 ± 0.26
S4	4.47	3.91	4.04	4.47	3.74	4.26	4.08	4.13	4.61	4.19 ± 0.28
S5	4.38	3.95	3.79	4.54	3.89	4.45	4.35	4.01	4.47	4.20 ± 0.29
S6	4.45	3.78	3.78	4.24	3.54	4.10	4.10	3.94	4.53	4.05 ± 0.32
S7	4.26	3.73	3.62	4.15	3.59	4.23	4.36	3.94	4.27	4.01 ± 0.30
S8	4.22	3.44	3.58	3.83	3.09	3.65	4.13	3.86	4.36	3.79 ± 0.40
S9	4.00	3.35	3.31	3.81	3.03	3.74	4.13	3.67	4.11	3.68 ± 0.38
S10	3.94	2.96	3.10	3.41	2.76	3.39	3.85	3.52	4.05	3.44 ± 0.45
S11	3.81		2.99	3.57	2.69	3.30	3.57	3.31	3.84	3.38 ± 0.39
S12	3.68		2.73	3.23		2.99	3.03	3.10	3.65	3.20 ± 0.35
S13	3.44			3.18				2.87	3.56	3.26 ± 0.30
X	4.17 (0.40)	3.82 (0.51)	3.60 (0.48)	4.09 (0.66)	3.58 (0.67)	3.99 (0.61)	4.04 (0.43)	3.80 (0.51)	4.27 (0.42)	3.89 (0.49)

G: Gymnast; LS: Last step; S: Step, x: mean value; sd: standard deviation

Table 3. *Data on the average step velocity (m/sec) for each gymnast across 6 attempts on handspring vault.*

Step	G1	G2	G3	G4	G5	G6	G7	G8	G9	x ± sd
LS	8.78	8.79	7.55	8.21	7.77	8.40	8.32	7.75	7.79`	8.15 ± 0.46
S2	7.05	7.35	7.05	7.17	6.91	8.07	7.53	7.09	7.25	7.27 ± 0.35
S3	7.33	7.44	6.90	7.38	7.20	7.86	7.67	6.90	7.55	7.35 ± 0.32
S4	7.29	7.17	7.04	7.09	6.78	7.44	7.67	6.75	7.30	7.17 ± 0.29
S5	6.95	6.65	6.43	7.33	6.60	7.27	7.35	6.53	7.16	6.91 ± 0.37
S6	6.57	6.44	6.25	6.46	6.25	7.19	5.94	5.89	6.78	6.41 ± 0.40
S7	6.16	6.04	5.85	6.78	5.96	6.58	6.96	5.69	6.64	6.29 ± 0.45
S8	5.92	5.47	5.25	6.51	5.19	5.84	6.00	5.54	6.74	5.82 ± 0.53
S9	5.54	4.97	4.79	6.11	5.14	6.37	5.82	5.16	6.14	5.56 ± 0.57
S10	5.46	4.56	4.24	5.75	4.50	5.32	5.30	4.80	5.43	5.04 ± 0.52
S11	4.70		3.31	5.30	3.81	4.79	4.60	4.18	5.21	4.48 ± 0.68
S12	4.40		3.11	4.42		4.13	3.50	3.90	4.78	4.03 ± 0.57
S13	3.70			4.60				3.28	3.96	3.88 ± 0.55

G: Gymnast; LS: Last step; S: Step, x: mean value; sd: standard deviation

DISCUSSION

The contribution of this research is particularly important since it recorded the entire run-up phase of the gymnasts, unlike most other studies that focus on only the last two to four steps. Variations in the length of the final strides are attributed to the visual adjustments athletes make to precisely approach the vault. The run-up phase for the gymnasts ranged from 21.15m to 24.26m (average: 23.16 ± 0.85m) and comprised 10-13 strides. The average run-up length was 23.16m, with an average of 12.11 steps, a step length (SL) of 1.67m, a step frequency (SF) of 3.93 steps/sec, and a step velocity (SV) of 6.18 m/sec. The average length of the hurdle step was 3.01m, consistent with estimates for Olympic male gymnasts (Uzunov, 2007). Our findings regarding the run-up distance are comparable to those of Heinen et al. (2013), who reported an average approach-run distance of 19.56 ± 0.29m to the leading edge of the vaulting table.

The results revealed a progressive increase in velocity from the first to the last step, which is a key requirement of the run-up phase. However, a slight decrease of -1.08% was observed in the penultimate step (7.35 vs. 7.27 m/sec). This increase in velocity is primarily due to the rise in step length (SL) (Thorstensson & Roberthson, 1987) and step frequency (SF) (Kuitunen et al., 2002). The mean velocity of 8.15 m/sec at the last step is consistent with findings from Van der Eb et al. (2012), who reported similar values (8.00 ± 0.6 m/sec), and Milčić et al. (2019), who noted a velocity of 8.06 m/sec for high-level gymnasts performing the handspring vault. This value also falls within the range of 7.50 to 9.95 m/sec reported in other studies (Brehmer & Naundorf, 2011; Fujihara, 2016). It is noteworthy that our gymnasts employed similar tactics in the final steps before the hurdle step, reinforcing previous findings (Heinen et al., 2013; Veličković et al., 2011) which reported an increase in velocity during these last steps. Specifically, Veličković et al. (2011) observed that top-level and middle-class gymnasts exhibited the highest velocity values on the final step when performing complex vaults, such as the Handspring forward and salto forward straight with 5/2 turns, or the Roche with a ½ turn. This progressive increase in run-up velocity, peaking in the last stride or the final two strides, has been documented in other studies (Velickovic, Petkovic, & Petkovic, 2011; Sands & Cheetham, 1986), with gymnasts maintaining their velocity in the last 5 meters (Arkaev & Suchilin, 2004). Any fluctuations in speed may be attributed to the necessary visual adjustments athletes make to align their approach to the springboard (Bradshaw, 2004). This is consistent with previous studies indicating that gymnasts aim to reach the springboard at the highest possible velocity (Bradshaw, 2004). Additionally, Velickovic et al. (2011) found that top-level gymnasts demonstrated a gradual increase in velocity, peaking at 9.95 m/sec in the final step of the approach run, which is higher than the 8.57 m/sec reported for high-level gymnasts and the 8.15 m/sec observed in our study. The 8.15 m/sec recorded in our study aligns with findings by Tan et al. (2023), who reported a mean velocity of 7.87 ± 0.48 m/sec during the final 5 meters of the run-up for handspring vault performance.

However, our results contrast with those of Veličković et al. (2011), who observed a decrease in velocity in the middle of the run-up among elite gymnasts, while our findings show a continuous increase in average run-up velocity. It is important to note that achieving maximum velocity just before take-off from the springboard facilitates the subsequent execution of the first flight phase (Fernandes et al., 2016). Furthermore, the development of effective propulsion for a successful first flight phase significantly relies on the velocity attained during the last step of the hurdle step (Dallas & Theodorou, 2020).

However, it is confirmed that gymnasts do not adopt the same tactics as track and field athletes regarding the length of the final three steps. A shorter length of the last step could negatively impact both the approach angle to the springboard and the angle of the first flight phase. Instead, gymnasts aim to increase the length of the last step to minimize the loss of horizontal speed in the subsequent phase. During the run-up, gymnasts meticulously adjust their approach to the springboard, leading to a reduction in length in the last two strides as they visually fine-tune their final steps. This finding aligns with previous studies on high-level male (Dallas & Theodorou, 2020) and female gymnasts (Heinen, 2011; 2013), as well as the Yurchenko vault (Bradshaw, 2004), which emphasize the need for precise distance and timing adjustments during the last strides and the subsequent hop-to-foot phase (Meeuwsen & Magill, 1987).

Finally, some limitations of this study should be highlighted.

First, the handspring vault is a relatively simple maneuver for high-level gymnasts, and despite the provided instructions, participants may not have exerted maximal effort to develop their running velocity. Second, the infrequent practice of the handspring vault before the study could have impacted their performance effort. Third, the study did not examine other phases of the vault or assess technical performance, which limits the comprehensiveness of the analysis.

Moreover, the results may not be broadly applicable. The participants were high-level male artistic gymnasts performing under training conditions. Given the small sample size, the findings should be generalized with caution, considering that high-level athletes might share similar run-up execution patterns. Future research should explore kinematic characteristics in high-level female gymnasts and in younger gymnasts performing vaults with varying difficulty levels.

CONCLUSIONS

The results of the present study demonstrated a progressive increase in the gymnasts' velocity throughout the entire run-up, culminating in the last stride before the hurdle step. Additionally, the technique observed in the final three steps of the run-up was characterized by variations in step length: the last step was shorter than the penultimate step, while the penultimate step was longer than the one preceding it.

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THE RELATIONSHIPS AMONG GYMNASTS' TRAINING AGE, BODY MASS INDEX, BALANCE CONTROL, AND GYMNASTICS PERFORMANCE

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Abstract

The aim of the study was the examination of the relationships among gymnasts' training age, body mass index (BMI), balance control during the execution of handstand, standing scale forward, and stork standing in relevé position, and their performance in competition settings. Forty young competitive gymnasts (20 males; age: 12.20 ± 1.98 years, and 20 females; age: 12.33 ± 2.07 years, mean ± SD) participated in this study. A portable digital platform for posturography was used to measure maximal pressure, center of pressure (CoP) sway area, CoP linear distance displacement and CoP velocity. The resulting data were analyzed using an integrated software module (Foot Checker, version 4.0). The results confirm the reliability of the measurements. Strong positive correlations were found between gymnasts' performance in the gymnastics competition, and their training age and BMI, with relationships also identified between performance and variables related to balance control. Regression analysis revealed that gymnasts' training age, BMI, and balance control in performing the assessed gymnastics skills had predictive significance in determining their performance in the competition, taking into account differences between age groups. Despite the limitations of the study, the results represent a valuable contribution to the literature by expanding knowledge about predicting gymnastics performance in competition. Furthermore, the results provide evidence for the identification of talent in gymnasts, offer coaches insights to improve training efficiency, and provide recommendations for future research in this area.

Keywords: *gymnastics competition, prediction, gymnasts, balancing ability, posturography.*

INTRODUCTION

High-level gymnastic skills are characterized by increased stability, precise posture control during the execution of different movements, and reduced variability in their acceleration time-series. Even minor disruptions to stability can significantly impact gymnastics performance (Asseman, Caron, & Crémieux, 2008; Lamoth, van Lummel, & Beek 2009). Fundamental gymnastics balance skills such as (a) the handstand, (b) the standing scale, scale forward, or front scale, and (c) the standing scale on one leg extended on the ball of the foot (relevé) with the other leg in passé (stork standing in relevé position) – are crucial for ensuring the quality and safety of gymnastics execution and determine the potential for high-level development and performance (Asseman et al., 2008; FIG, 2020a; FIG, 2020b; Fink, Hofmann et al., 2021; Fink, Lopez et al., 2021; Hedbávný, Sklenaříková, Hupka, & Kalichová, 2013; Hrysomallis, 2011; Uzunov, 2008; Živčić-Marković, Krističević, & Aleksić-Veljković, 2015).

Given the essential role these skills play in attaining proficiency in gymnastics, targeted training to develop and perfect these skills is recommended from a young age, typically around 7 years old (Fink, Hofmann et al., 2021; Fink, Lopez et al., 2021). Gymnasts' experience, competition level, number of training hours, and body mass index (BMI) percentiles are associated with their balance control (Liaw, Chen, Pei, Leong, & Lau, 2009; Olchowik et al., 2015; Opala-Berdzik, Głowacka, & Juras, 2021) and have been considered among the most important factors in predicting success in gymnastics (Asseman et al., 2008; Hrysomallis, 2011; Kaur & Koley, 2019; Opala-Berdzik et al., 2021; Vuillerme, Teasdale, & Nougier, 2001; Zemková & Zapletalová, 2022).

Training programs that include a combination of general and sport-specific exercises, specifically targeting postural and core muscles, have demonstrated positive outcomes in terms of improved body balance, increased strength in the back muscles, and enhanced endurance. Research has indicated that incorporating balance training into activities of recreational active individuals or physical education students led to enhancements in vertical jump performance (Kean, Behm, & Young, 2006; Šimek, Milanović, & Jukić, 2007), agility (Šimek et al., 2007), and shuttle run (Yaggie & Campbell, 2006). However, it is not well established whether these improvements effectively translate into enhanced athletic performance (Zemková & Zapletalová, 2022) or how balance training influences the motor skills of elite athletes (Hrysomallis, 2011). Demonstrating a positive impact on athletic performance could further justify incorporating balance training into a comprehensive conditioning regimen (Hrysomallis, 2011).

Gymnasts exhibit excellent neuromuscular control in maintaining posture and core stability. Additionally, they possess a heightened ability to perceive their body's orientation in space, particularly during tasks that require precise postural adjustments. These attributes significantly enhance their efficiency in executing gymnastics-specific movements and overall functional performance (Vuillerme et al., 2001).

Researchers have employed multiple tests to evaluate balance when exploring the relationship between balance ability and athletic performance. The center of pressure (CoP) measurement, obtained through a pressure or force assessment system, is currently the most reliable method for accurately quantifying standing balance (Asseman et al., 2008; Milosis & Siatras, 2012; Milosis & Siatras, 2023). Reduced ranges of CoP displacement indicate improved postural control during the performance of a specific balance position (Asseman et al., 2008; Asseman, Caron, & Crémieux, 2005). In contrast, displacement velocity reflects the effectiveness of the nervous system in regulating the musculoskeletal system's response to momentary imbalances, where a lower average velocity of CoP displacement suggests superior postural control (Asseman, Caron, & Crémieux, 2004).

Within this context, there is a lack of scientific data on the interrelationship between gymnasts' balance ability and gymnastics performance. Therefore, the aim of this study was to determine the correlations between the training age, BMI, and balance control of gymnasts and their performance in gymnastics age-group competitions. It was expected that the results of this study would provide coaches with valuable insights to optimize their gymnasts' training programs more effectively.

METHODS

Forty young competitive gymnasts (20 males; age: 12.20 ± 1.98 years, body mass: 35.55 ± 10.09 kg, height: 142.05 ± 12.90 cm, and 20 females; age: 12.33 ± 2.07 years, body mass: 36.15 ± 6.29 kg, height: 145.50 ± 8.20 cm; mean ± SD) participated in this study. The study included only those gymnasts who were able to maintain a stable base of support and good posture while performing the required skills for at least 10 seconds. The participants had undergone structured training and competitive gymnastics at the national level for a period ranging from 4 to 11 years. Typically, young gymnasts can achieve the skill of maintaining a static handstand on a flat surface, such as the floor, after undergoing specific gymnastics training for 3 to 4 years (Kochanowicz et al, 2015). The gymnasts trained six days per week, with each training session lasting around three hours, and they practiced on every gymnastics apparatus. Training took place in a well-equipped gym, also utilized by the Hellenic national gymnastics team. The older gymnasts, male and female, aged 14 and 15 years, were deemed elite by the Hellenic Gymnastics Federation. The study adhered to the guidelines set by the Ethical Committee of Aristotle University of Thessaloniki. Before any measurements were taken, the parents provided written informed consent for their children's participation in the study.

The distribution of weight and stability during a handstand was measured and analyzed using a vertical posturographic digital platform (Foot Checker, Comex S.A./LorAn Engineering Srl; Castel Maggiore, Bologna, Italy). The platform measured 700 x 500 mm and was positioned on the floor. It comprised 2304 resistive elements with a measurement accuracy of 0.001 kPa, sampled at a frequency of 60 Hz. Maximal pressure (the amount of force acting vertically on the support surface; kPa), CoP mean velocity (the sum of the cumulative CoP displacement divided by the total time; mm/s), and center of pressure (CoP) sway area (defined as an ellipse containing 90% of all displacement points; mm^2) were analyzed using integrated software (Foot Checker, version 4.0).

All measurements were conducted under identical experimental conditions for all participants. The tests were carried out by a single researcher in a dedicated room that minimized distractions for the gymnasts. The portable platform used for the measurements was placed in a marked area. To prevent the effects of training fatigue on the results, the tests were conducted in the afternoon, before the start of the training session. Following a brief warm-up, the participants stood still on the platform with their eyes open for 10 seconds during each test. A two-minute rest period between trials was applied, and all tests were conducted without shoes. A failed attempt was considered when, during the 10-second standing period, there was any variation in the support position, such as shuffling, stepping, or falling. In such cases, the effort was interrupted and repeated after a two-minute rest.

During the standing scale forward, participants were instructed to place their dominant foot in the middle of a rectangular taped area on the platform and slightly lower their upper body. They were then asked to raise their non-dominant leg backward to the horizontal level.

For the stork standing in relevé position, participants stood in the same place with their dominant foot positioned in the center of the platform within the rectangular taped area. They were then asked to place their hands on their hips and position their non-supporting foot against the inside of their supporting leg's knee. Following this, participants were instructed to raise the heel of their supporting foot to balance on the toe. The evaluation began as the heel was lifted from the platform. After completing the test, participants performed the same standing scale on their other leg. All participants were instructed to maintain balance in the same way (by looking straight ahead, with eyes open, and keeping their bodies as still as possible).

To assess handstand balance, the “press to handstand hold” technique was utilized, starting from a standing position with feet apart and hands positioned shoulder-width apart on the platform. Under the guidance of the researcher, the gymnast was assisted in attaining a stable handstand with correct body alignment, with the experimenter lightly touching the sides of their upper legs. The gymnast’s legs were then “released,” and the assessment was conducted and recorded for 10 seconds. The duration of 10 seconds for the handstand test was considered adequate for the goals of the present study, achievable by the participating gymnasts, and has also been applied in previous studies (Kochanowicz et al., 2015). During the test, gymnasts attempted to maintain a stable base by holding still with their wrists and fingers, fixing their gaze within the hand support and in front of the wrists, while keeping their head in a neutral position (Asseman et al., 2005), ensuring that their arms remained straight and their bodies tight, strong, and stable.

The SPSS software (SPSS v. 28, SPSS Statistics, IBM Corp., NY) was used to perform all statistical analyses. To verify the reliability of the measurements, all tests were repeated twice (test-retest) under the same conditions by the same experienced examiner within a one-week period. Test-retest reliability was examined using the intra-class correlation coefficient (ICC). The means and standard deviations of the values for the left and right extremities from the two tests were used to analyze the examined variables related to balance control: (a) Maximal Pressure (kPa) of the hands during handstand (MP_H), Center of Pressure (CoP) mean velocity (mm/s) during handstand (CoP_V_H), and CoP sway area (mm^2) during handstand (CoP_SA_H); (b) Maximal Pressure of the foot during stork standing in relevé (MP_SSR), CoP mean velocity during stork standing in relevé (CoP_V_SSR), and CoP sway area during stork standing in relevé (CoP_SA_SSR); and (c) Maximal Pressure of the foot during standing scale forward (MP_SSF), CoP mean velocity during standing scale forward (CoP_V_SSF), and CoP sway area during standing scale forward (CoP_SA_SSF). Figure 1 displays examples of the measurements of the variables during the execution of the studied skills. The results of the national age group competition were recorded approximately six months after the introduction of the measurements. To facilitate the statistical analyses, the mean values were calculated for the six male apparatuses and the four female apparatuses.

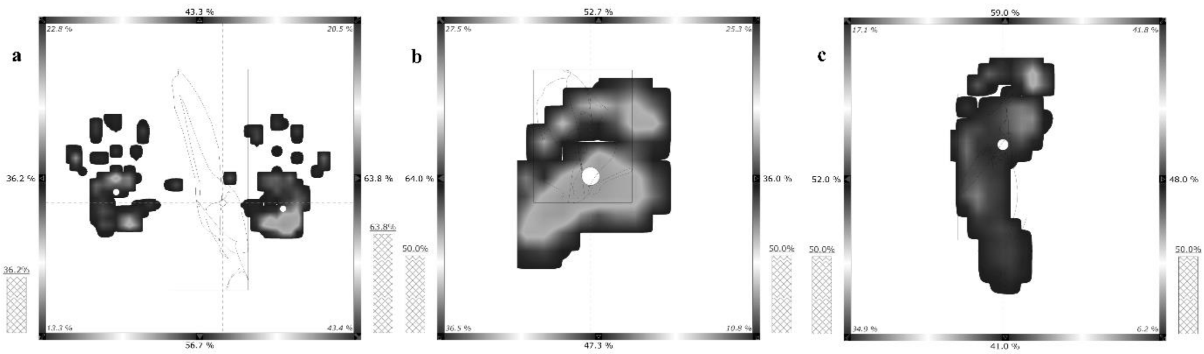

Figure 1: Examples of the measurements of the variables during the execution of the studied skills on the digital platform (a) handstand, (b) stork standing in Relevé, and (c) standing scale forward.

RESULTS

Assumptions and reliability of the measurements

The criteria for a normal distribution were met by the independent variables, as evidenced by their skewness and kurtosis falling within the acceptable range (-1.0 to +1.0), and the Shapiro-Wilk test supported the normal distribution of the examined variables ($p > .05$). The single measures intra-class correlation coefficient values ranged from .66 to .96. The equality of variance-covariance matrices among groups was confirmed by Box's test. Similarly, Bartlett's test of sphericity revealed that the variances were equivalent across groups, and Levene's test demonstrated that there was no significant difference in error variance among groups ($p > .05$).

Relationships between training age, BMI, balance control parameters and gymnastics performance

Pearson's correlation coefficients showed significant correlations between the performance of participants in the gymnastics competition and their training age, BMI, and balance control in the three examined gymnastics skills, ranging from low negative to high positive (-.31 to .91, Table 1).

The normal P-P plot supported the normality of the data, and the scatterplot of the residuals indicated homoscedasticity. Tolerance values between 0.122 and 0.715 and VIF values ranging from 1.399 to 8.193 indicated acceptable collinearity (Vittinghoff, Glidden, Shiboski, & McCulloch, 2005). The Durbin-Watson test result of 2.031 (within the acceptable range of 1.5 to 2.5) confirmed the independence of errors. The results from the regression analysis showed that training age and BMI emerged as significant predictors of gymnasts' performance, accounting for 41.5% of the variance in performance, $F(2,37) = 13.15$, $p < 0.001$. Adding MP_H, CoP_V_H, and CoP_SA_H in the second step accounted for an additional 3.2% of variation in performance, $F(3,34) = 0.65$, $p = 0.587$. Including MP_SSR, CoP_V_SSR, and CoP_SA_SSR in the third step accounted for an additional 16% of variation in performance, $F(3,31) = 4.22$, $p < 0.01$. Finally, adding MP_SSF, CoP_V_SSF, and CoP_SA_SSF in the fourth step accounted for an additional 6.3% of variation in performance, bringing the total proportion of explained variance to 67.1%, $F(3,28) = 1.79$, $p = 0.173$. The results from the analysis of variance (ANOVA) table confirmed that the model significantly predicted the dependent variable in all steps: $F(2,37) = 13.15$, $p < 0.001$; $F(5,34) = 5.50$, $p < 0.001$; $F(8,31) = 6.00$, $p < 0.001$; and $F(11,28) = 5.18$, $p < 0.001$ (Table 2). The equation generated by the regression model to predict gymnastics performance based on balance control in the three examined gymnastics skills was calculated as follows:

Gymnastics performance = -11.192 + (0.217 × training age) – (0.092 × BMI) + (0.004 × MP_H) + (0.039 × CoP_V_H) + (0.001 × CoP_SA_H) + (0.087 × MP_SSR) – (0.125 × CoP_V_SSR) + (0.009 × CoP_SA_SSR) + (0.007 × MP_SSF) + (0.018 × CoP_V_SSF) – (0.002 × CoP_SA_SSF).

Table 1

Descriptive statistics and correlations for study variables

Variable	M	*SD*	1	2	3	4	5	6	7	8	9	10	11	12
1. Performance	10.95	1.45	–											
2. Training age	6.38	2.30	.64***	–										
3. BMI	17.10	1.83	.51***	.74***	–									
4. MP_H	392.50	21.74	.30	.31*	.37*	–								
5. CoP_V_H	32.89	8.88	-.15	-.05	-.08	.32*	–							
6. CoP_SA_H	919.78	359.29	-.18	-.01	-.02	.43**	.75***	–						
7. MP_SSR	223.39	9.06	.56***	.36*	.37*	.17	-.42**	-.37*	–					
8. CoP_V_SSR	28.72	8.18	-.31*	-.21	-.26	-.07	.51***	.50***	-.58***	–				
9. CoP_SA_SSR	337.90	148.55	-.17	-.14	-.19	.01	.49***	.46**	-.56***	.91***	–			
10. MP_SSF	183.38	23.75	.20	.28	.30	.18	-.19	-.08	.00	-.04	-.02	–		
11. CoP_V_SSF	44.96	13.74	-.39*	-.43**	-.11	-.45**	.54***	-.48**	-.38*	.61***	.53***	-.32*	–	
12. CoP_SA_SSF	896.11	387.60	-.42**	-.44**	.04	-.29	.54***	-.46**	-.34*	.53***	.58***	-.24	.73***	–

Abbreviations: M = mean; SD = standard deviation; BMI = body mass index; MP_H = maximal pressure of the hands during handstand; CoP_V_H = center of pressure mean velocity during handstand; CoP_SA_H = center of pressure sway area during handstand; SSS = stork standing in relevé, SSF = standing scale forward.

****p < .001, **p < .01, *p < .05.*

Table 2
Hierarchical regression results for gymnastics performance in the age group competition

Variable	B	95% CI for B		SE B	β	R^2	AdjR^2	*t*
		LL	UL					
Step 1						.42	.38	
Constant	7.62	3.48	11.75	2.04				3.73***
Training age	0.37	0.13	0.61	0.12	.59			3.16**
BMI	0.06	-0.24	0.36	0.15	.07			0.38
Step 2						.45	.37	
Constant	7.23	-0.85	16.03	4.22				1.81
Training age	0.37	0.13	0.62	0.12	.59			3.12**
BMI	0.47	0.13	0.62	0.16	.06			0.31
MP_H	0.00	-0.02	0.02	0.01	.02			0.14
CoP_V_H	0.01	-0.06	0.07	0.03	.03			0.15
CoP_SA_H	-0.00	-0.00	0.00	0.00	-.19			-0.92
Step 3						.61	.51	
Constant	-6.70	-20.52	7.13	6.78				-0.99
Training age	0.33	0.10	0.56	0.11	.53			2.95**
BMI	-0.09	-0.39	0.21	0.15	-.11			-0.61
MP_H	0.00	-0.02	0.02	0.01	.06			0.38
CoP_V_H	0.02	-0.04	0.08	0.03	.10			-0.58
CoP_SA_H	0.00	-0.00	0.00	0.01	-.10			0.51
MP_SSR	0.07	0.02	0.12	0.02	.45			2.96**
CoP_V_SSR	-0.09	-0.18	0.02	0.05	-.51			-1.74
CoP_SA_SSR	0.01	0.00	0.01	0.00	.61			2.09*
Step 4						.67	.54	
Constant	-11.19	-25.68	3.29	7.07				-1.58
Training age	0.22	-0.04	0.48	0.13	.34			1.70
BMI	-0.09	-0.40	0.22	0.15	-.12			-.60
MP_H	0.00	-0.02	0.03	0.01	.07			.44
CoP_V_H	0.04	-0.02	0.10	0.03	.24			1.30
CoP_SA_H	0.00	-0.00	0.00	0.00	-.07			-.40
MP_SSR	0.09	0.00	0.04	0.03	.55			3.56***
CoP_V_SSR	-0.13	-0.24	-0.01	0.06	-.71			-2.27*
CoP_SA_SSR	0.01	0.01	0.02	0.00	.90			2.91**
MP_SSF	0.01	-0.01	0.02	0.01	.12			.89
CoP_V_SSF	0.02	-0.03	0.06	0.02	.17			.81
CoP_SA_SSF	-0.00	-0.00	0.00	0.00	-.42			-2.13*

Abbreviations: CI = confidence interval; LL = lower limit; UL = upper limit; BMI = body mass index; MP_H = maximal pressure of the hands during handstand; CoP_V_H = center of pressure mean velocity during handstand; CoP_SA_H = center of pressure sway area during handstand; SSS = stork standing in relevé, SSF = standing scale forward.
****p < .001, **p < .01, *p < .05.*

DISCUSSION

This study aimed to determine the relationships between gymnasts' training age, BMI, and balance control, and their performance in age group competitions. Currently, the most reliable approach to accurately quantify balance is through the measurement of the center of pressure (CoP) using a pressure or force assessment system

(Asseman et al., 2008; Milosis & Siatras, 2012; Milosis & Siatras, 2023). The findings of this study supported the reliable and effective use of the portable posturographic digital platform as a tool for measuring CoP in assessing balance skills in gymnastics settings (ICC ranged from .66 to .96).

In this study, strong positive correlations were found between gymnasts' performance in competitions and both training age (r = 0.64) and BMI (r = 0.51). Additionally, relationships were identified between performance and variables related to balance control. In particular, positive correlations were observed with maximal pressure, which refers to the vertical force exerted on the support surface during the performance of the studied gymnastics skills. These correlations were robust and statistically significant, especially concerning stork standing in relevé position (r = 0.56). Conversely, this study revealed negative relationships between performance and the CoP mean velocity and CoP sway area during the execution of the examined gymnastics skills. These correlations were of moderate strength and statistical significance, particularly regarding stork standing in relevé position (r = -0.31) and standing scale forward (r = -0.39, -0.42). Higher maximal pressure and lower CoP mean velocity and sway area are mentioned as determinants of better-quality balance control (Asseman et al., 2004; Asseman et al., 2005; Asseman et al., 2008; Hrysomallis, 2011; Sobera, Serafin, & Rutkowska-Kucharska, 2019; Yeadon & Trewartha, 2003). Significant correlations have been identified between balance ability and a range of performance measures (Hrysomallis, 2011).

The results of the present study support the hypothesis that effective development of postural control skills is crucial for young gymnasts to attain proficiency in fundamental movement skills (Clark, 2005; Lubans, Morgan, Cliff, Barnett, & Okely, 2012) and enhance their overall athletic performance (Hrysomallis, 2011; Zemková & Zapletalová, 2022). It has been shown that the enhanced postural stability observed in artistic gymnasts is associated with their training experience and BMI percentiles (Liaw et al., 2009; Olchowik et al., 2015; Opala-Berdzik et al., 2021). Several studies have demonstrated the substantial influence of professional gymnastic training on body stability, both in natural and unnatural balance positions (Gautier, Thouvarecq, & Larue, 2008; Hedbávný et al., 2013; Kochanowicz et al., 2018). Furthermore, it has been argued that the strength relative to the body mass of gymnasts plays a decisive role in their performance in gymnastics (Bradshaw & Rossignol, 2004; Kaur & Koley, 2019).

In addition, the results of the regression analysis revealed that gymnasts' training age, BMI, and balance control during the performance of the studied gymnastics skills had predictive significance in determining their performance in age group competitions. The equation generated by the regression model can be used to predict performance in competition based on gymnasts' training age, BMI, and balance control during the execution of the studied gymnastics skills.

Based on the findings, the model demonstrated significant predictive ability for the dependent variable (performance in the competition) across all stages, accounting for a substantial 67.1% of the variance in the final step. An examination of the beta coefficients in the final step concluded that the CoP sway area, CoP mean velocity, and maximal pressure during stork standing in relevé, as well as the CoP sway area during the execution of standing scale forward, made the most substantial contributions to predicting performance in competition. These findings indicate that the skill of stork standing in relevé holds greater significance for performance compared to standing scale forward and handstand skills. The handstand is widely acknowledged as an essential balancing skill for both male and female gymnasts (Hedbávný et al., 2013; FIG, 2020a; FIG, 2020b; Uzunov, 2008; Živčić-Marković et al., 2015). It serves as a versatile position, utilized as both the initial and final posture in various gymnastic exercises. For example, it is a fundamental element within larger motor sequences, such as executing a forward or backward handspring. It is also used in other gymnastic exercises, such as transitioning from a swing with straight arms to a handstand on rings or executing a basket to handstand on parallel bars. However, the findings from the present study indicate that balance control during the execution of a handstand does not significantly predict performance outcomes in competition. The wide age range and inclusion of both genders among the young gymnasts in this study may have influenced the results, thereby downplaying the predictive validity of the handstand on their performance, particularly when considering the effects of the other variables studied.

The extent to which improvements in performance can be attributed to the specific balance training stimulus, rather than the overall increase in physical conditioning resulting from integrating balance training, remains uncertain. Some theories suggest that advancements in balance skills might decrease the allocation of muscles for stabilization purposes, enabling them to contribute more effectively to generating motive force (Kean et al., 2006). Significant improvements in motor skill performance have been observed as a result of balance training, indicating notable adaptations (Hrysomallis, 2011). Furthermore, evidence suggests that balance training can enhance maximum voluntary isometric contraction (MVIC) force (Heitkamp et al., 2001), improve the rate of force development (RFD) during MVIC (Gruber & Gollhofer, 2004), and potentially optimize musculotendinous and joint stiffness, thereby reducing the amortization phase in the stretch-shortening cycle (Kean et al., 2006).

Moreover, engaging in balance training can result in specific neural adaptations at both spinal and supraspinal levels. These adaptations include the suppression of spinal reflex excitability (Taube et al., 2008), as well as improved agonist-antagonist muscle co-contraction, leading to increased joint stiffness and enhanced joint stability against disturbances (Lloyd, 2001). Additionally, balance training has been associated with a shift in movement control, transitioning from cortical structures to subcortical and cerebellar regions, as supported by research findings (Taube et al., 2008). Lastly, several sensory adaptations to the balance training stimuli inherent in various sports activities have been proposed (Hrysomallis, 2011; Vuillerme et al., 2001).

Nevertheless, while these task-specific adaptations can account for the enhanced balance ability resulting from balance training, they may not fully elucidate the concurrent improvement in motor skills. The specific contribution of enhanced motor or sensory function to the improvement in motor task performance from balance training remains unclear. Proprioception, a component of the sensory system, provides information about joint position sense and detects joint motion, making it a crucial element of the balance system (Fallas-Campos et al., 2023; Vuillerme et al., 2001). It has been suggested that athletes may develop increased skill in focusing on and attending to relevant sensory cues through training, thereby enhancing their ability to generate precise motor responses. For example, gymnasts who balance on the beam may learn to prioritize their attention to detect even the slightest body segment acceleration, aiming to minimize unnecessary motion and ultimately enhance their performance (Ashton-Miller et al., 2001). Specifically, the ability to reduce CoP displacements through the reinsertion of proprioceptive information is more pronounced in gymnasts compared to non-gymnasts (Vuillerme et al., 2001).

A limitation of this study was the inclusion of a sample consisting of both male and female gymnasts, which was necessary to ensure an adequate size for statistical analyses. However, it is possible that the balance skills studied had different effects on gymnastics performance between genders. For instance, the handstand may have a more prominent impact on the performance of male gymnasts due to its greater utilization in skills performed on male apparatus. Conversely, the standing scale forward and stork standing in relevé position may be more strongly associated with female performance, as these skills are fundamental for executing balances, turns, and jumps on the floor and balance beam.

Furthermore, this study included a wide range of athletes, encompassing individuals aged approximately 10 to 15 years with varying levels of training experience (4 to 9 years). While the gymnasts participated in a gymnastics age group competition, it is important to recognize that differences in age and training experience likely influence the relationships between balance control and performance results. Further research is needed to explore the relationship between balance ability and gymnastics performance in male and female gymnasts separately. Additionally, employing larger and more homogeneous samples regarding age and training experience would enhance the validity of the findings.

CONCLUSIONS

The results of this study revealed that variables such as the gymnasts' training age, BMI, and balance control during the execution of handstands, stork standing in relevé position, and standing scale forward had a positive predictive relationship with their performance in upcoming competitions. Demonstrating a positive impact on athletic performance strengthens the rationale for integrating balance training as a critical component of a comprehensive conditioning program. Based on these findings, incorporating static balance tests of specific skills could also be beneficial in the talent identification process for selecting promising gymnasts during early specialization. Furthermore, these tests may serve as valuable assessment tools for evaluating and identifying high-performance gymnasts.

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SPORTS INJURIES IN YOUNG GYMNASTS FOLLOWING THE COVID-19 ONSET: PREVALENCE AND ASSOCIATED FACTORS

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Abstract

COVID-19 lockdowns had a negative impact on training practices and other fitness- and coaching-related aspects across many sports disciplines. This study analyzed the relationship between different training routines and performance, as well as the prevalence of musculoskeletal injuries (MI) in young gymnasts following the onset of the COVID-19 pandemic. The sample consisted of 67 artistic gymnasts (AG) from Campo Grande, MS, Brazil, aged 8 to 17 years. Participants were divided into two groups: G1, which included gymnasts in remote training, and G2, comprising gymnasts in face-to-face training. Subjects were assessed for anthropometric variables, flexibility, muscle power, and sensorimotor stability, and completed a questionnaire to record MI cases. A total of 34 MI cases were reported by 23 participants (34.3%), with the majority affecting the lower limbs. Eight individuals reported at least two retrospective MI cases. Additionally, G2 demonstrated higher muscle power, greater flexibility, and improved sensorimotor stability. Face-to-face training conditions were associated with at least a tenfold increase in the likelihood of MI. Weekly training time (exposure) was linked to a ~9% increase in lower limb MI, while factors such as age, dynamic balance, and training were directly associated with MI occurring during floor exercises.In conclusion, although regular face-to-face training was linked to enhanced motor performance, it was also associated with a higher prevalence of MI, particularly in the lower limbs. Floor exercises were the primary circumstances under which injuries occurred.

Keywords: *gymnastics; training setting; COVID-19; performance; sports injuries.*

INTRODUCTION

Artistic gymnastics (AG) requires a combination of artistic expression with physical and biomechanical effort (Gasparetto et al., 2022; Moeskops et al., 2019). Gymnastics, in general, has the youngest average age of single-sport specialization at 8.9 years and is one of the few sports where early specialization has been associated with higher rates of elite-level competition (Myer et al., 2016). Women's artistic gymnastics includes floor exercise, uneven bars, balance beam, and vault, while men's includes floor exercise, parallel bars, rings, pommel horse, horizontal bar, and vault. These exercises are brief but high-intensity, consisting of gymnastics elements—complex movements that involve extreme ranges of motion and generate high forces (Desai et al., 2019; Gasparetto et al., 2022; Hernández-Beltrán et al., 2023).

Challenging AG elements require substantial strength, power, flexibility, and agility, all performed on various apparatuses (Campbell et al., 2019; Gasparetto et al., 2022; Moeskops et al., 2019). Enhancing AG performance is typically linked to significant overloads, often sustained through repetitive training and competition exposure. Athletes may train between 16 and 40 hours per week, enduring a combination of these physical demands (Buckner et al., 2017; Moeskops et al., 2019; Sastre-Munar et al., 2022). Importantly, a combination of high training volumes and inadequate recovery intervals can compromise performance and is a potential contributor to the onset of sports-related musculoskeletal injuries (MI) (Boullosa et al., 2020; Campbell et al., 2019).

Musculoskeletal injuries (MI) have multiple adverse effects on athletic performance, including training interruptions, detraining, and significant medical costs (Hart et al., 2018; Ling et al., 2020). A review of injuries in gymnastics found that athletes are at higher risk of injury at more competitive levels, with increased training hours, and particularly if they participate in artistic gymnastics (Atiković et al., 2017; Sastre-Munar et al., 2022; Thomas & Thomas, 2019). MI incidence and prevalence are notably high among gymnasts, with 0.3 to 3.6 injury cases per athlete (Campbell et al., 2019). Younger age and participation in competitive settings have been linked to a higher injury risk (Tisano et al., 2022).

From an etiological perspective, MI results from complex interactions between external conditions and both modifiable and non-modifiable intrinsic risk factors (Boullosa et al., 2020; Kalkhoven et al., 2020). Additionally, a primary injury may impact motor performance, increasing the likelihood of recurrence or exacerbation of MI (Campbell et al., 2019; Nunes et al., 2021).

In this context, COVID-19 lockdowns negatively impacted training practices, affecting training frequency, duration, intensity, technique, recovery, and other fitness and coaching-related aspects across multiple sports modalities (Washif et al., 2022). Many athletes experienced significant reductions in training frequency and time spent on various training-related activities during remote training sessions, leading to notable disruptions in training and performance (Jagim et al., 2020; Patel et al., 2022). Moreover, remote and unsupervised training activities may be associated with a higher risk of sports injuries due to inadequate supervision and compromised training environments (Bobo-Arce et al., 2021; Pillay et al., 2020). However, these issues have been insufficiently investigated in epidemiological studies involving gymnasts.

The current investigation aimed to analyze the association between different training routines and performance parameters, as well as the prevalence of MI in young gymnasts following the onset of the COVID-19 pandemic. Additional objectives included characterizing sports injuries and exploring potential associations between MI occurrence and performance measures. Understanding the prevalence of injuries in artistic gymnastics is crucial for developing effective prevention strategies. By identifying intrinsic and extrinsic factors associated with MI, this study seeks to inform coaches, athletes, and healthcare professionals about targeted interventions to reduce injury rates and enhance athlete safety.

METHODS

The current investigation is a descriptive study based on a cross-sectional design. A convenience sample was drawn from gymnasts aged 8 to 18 years, representing two artistic gymnastics (AG) teams from Campo Grande, MS, Brazil. To be included, participants were required to have engaged in uninterrupted sports training for at least 30 days. Exclusion criteria included reporting a musculoskeletal injury at the time of the initial assessment, using medication for inflammatory processes or infections, and having known metabolic or cardiorespiratory diseases that disrupted AG training.

In total, 67 gymnasts from two AG training sites in Campo Grande participated in the study. Participants were divided into two groups (G) based on their training conditions: G1, consisting of gymnasts in remote training, and G2, comprising gymnasts in face-to-face training.

In terms of ethical considerations, the study adhered to the principles of the Declaration of Helsinki and the Nuremberg Code, as well as the research standards involving human subjects established by the National Health Council (CNS/Brazil). Participants, along with their parents and/or legal guardians, were provided with verbal and written information about the study before giving their consent by signing the informed consent forms. The research protocol was approved by the local ethics committee (Protocol 5.013.655/2021; CAAE 33562220.6.0000.0021).

After the initial approach, each participant completed a questionnaire providing descriptive information on individual characteristics, competitive level and category, retrospective training history, daily and weekly exposure to AG training, and participation in regular competitions.

For anthropometric characterization, body weight was measured using a mechanical scale (Welmy R-110, SP-BR). Height, both standing and sitting, was measured using a portable stadiometer (Personal Caprice Sanny Stadiometer, SP-BR) with participants in an anatomical reference position and the head aligned in the Frankfurt plane (Bacciotti et al., 2018). Body weight and height were used to calculate body mass index (BMI; mass(kg) ÷ height(m)^2) (Malina et al., 2013). Additionally, triceps and subscapular skinfolds were measured to estimate body composition. Body fat percentage (%F) was determined using an equation developed for children and adolescents (Slaughter et al., 1988).

Somatic maturation was assessed using a maturational offset, which estimates the time (in years) remaining to reach peak height velocity (PHV) (Mirwald et al., 2002).

Regarding physical-motor aspects, flexibility was assessed using the sit-and-reach test (Wells & Dillon, 1952). The Sargent Jump Test was employed to evaluate lower limb performance (Sargent, 1921), while upper limb performance was assessed by throwing a medicine ball (Cronin & Owen, 2004). Additionally, the Star Excursion Balance Test (SEBT) was used to evaluate dynamic balance (Robinson & Gribble, 2008). Postural balance was assessed with a force plate equipped with a 500 mm platform, four load cells, and a 100 Hz calibration system (BIOMEC 400_V4, EMG System®) (Scarmagnan et al., 2021). Participants performed the tests on both bipedal and unipedal supports and were instructed to maintain their position on the plate for 30 seconds, following previous protocols (Paterno et al., 2004; Scarmagnan et al., 2021).

Musculoskeletal injury (MI) cases were reported using a self-reported morbidity survey (Hoshi et al., 2008; Silveira et al., 2013). In this study, an MI case was defined as any physical complaint resulting from training and/or competition that prevented participation for at least one day, regardless of the need for medical care, as defined in previous studies (Kolt & Kirkby, 1999; Vanderlei et al., 2013). The morbidity survey gathered information on individual characteristics such as gender, duration of training, and details about past MI cases. Information on sports injuries included the affected anatomical site, injury mechanism, circumstances of onset, severity, time to return to normal training, and recurrence. Anatomical sites were categorized as head/neck, trunk, and upper or lower limbs. The injury mechanism was described based on the participant's perception of the contact or action that triggered the acute episode and/or the activity in which the symptoms were aggravated. The circumstance of injury onset was classified according to whether it occurred during training or competition (Vanderlei et al., 2013). MI recurrence was defined as present when a participant reported two or more retrospective MI cases.

Data normality assumptions were tested using the Kolmogorov-Smirnov test for quantitative variables. The Student’s t-test was used to compare parametric results between groups, while the Mann-Whitney test was applied for non-parametric results. Gender and musculoskeletal injury prevalence by group were analyzed using the Chi-square test (χ^2). An aggregated z-score, derived from individual z-scores of five variables, was used to describe postural balance results. Since these variables followed a normal distribution, they were analyzed using two-way repeated measures analysis of variance (Two-Way RM ANOVA) with Bonferroni’s correction. The Z-test was employed to compare proportions regarding musculoskeletal injury prevalence by anatomical site, onset circumstance, mechanism, and number of cases. Backward stepwise logistic regression models were used to evaluate the association between potential variables and four different sports injury outcomes. The predictive accuracy and performance of the logistic regression models were assessed using the area under the Receiver Operating Characteristic Curve (ROC curve). All statistical analyses were conducted with a significance level set at $p<0.05$.

RESULTS

Table 1 presents comparative results regarding general characteristics based on training schedule, with groups categorized as remote (G1) and face-to-face (G2). Both groups were similar in terms of age, anthropometric characteristics, and training experience. Weekly training exposure was higher in G2 compared to G1 ($p<0.001$). Although females were more prevalent in both groups, the remote training group had a higher proportion of males compared to the face-to-face training group ($p<0.05$). Regarding musculoskeletal injuries, a total of 34 MI cases were reported by 23 participants, resulting in a prevalence of 34.3%. G2 exhibited a higher prevalence of MI ($p=0.006$) and a greater number of injury cases than G1.

Next, figures 1A and 1B show the upper limb power and lower limb power values, respectively. While the upper limb power values were similar between groups, lower limb power was higher in G2 ($p=0.023$).

Figure 2 shows muscle flexibility and dynamic balance scores. For flexibility, G2 demonstrated higher scores compared to G1 (Figure 2A). However, there were no statistically significant differences in dynamic balance scores between or within the groups (Figure 2B).

Table 2 presents postural balance results by lower limb side. Within each group (side’s effect), both lower limb sides showed similar performance scores across all measurements ($p>0.05$). In intergroup comparisons, G2 participants exhibited lower sways, speeds, and areas compared to G1 on both sides.

Table 3 provides information on the characterization and prevalence of musculoskeletal injury (MI) cases. Descriptively, lower limb regions were the most common anatomical sites for MI onset, with a single MI case being the most frequently reported ($p>0.05$). Conversely, exercises on the floor were the primary circumstance associated with MI onset ($p<0.01$).

Table 1
General characteristics in accordance with group (n=67)

Variable	Group G1	Group G2	p-value
Age (years) [a]	10.9 ± 2.1	10.3 ± 2.1	0.339
Height (cm) [a]	144.1 ± 13.4	140.2 ± 12.7	0.250
Body weight (kg) [b]	35.5 (29.0 – 41.0)	37.0 (29.0 – 42.5)	0.800
BMI (kg/m^2) [b]	17.3 (16.1 – 18.3)	18.2 (16.6 – 20.3)	0.054
Body adiposity (%) [b]	13.2 (10.1 – 18.6)	15.3 (10.4 – 20.5)	0.526
Maturation [a]	12.95 ± 0.66	12.69 ± 0.74	0.168
Training practice (years) [b]	2.0 (2.0 – 4.0)	3.0 (1.8 – 4.3)	0.428
Week training time (h) [b]	2.0 (2.0 – 2.0)	6.0 (5.0 – 9.0)	<0.001 *
Gender			
Female	12 (54.5%)	37 (82.2%)	0.035 *
Male	10 (45.5%)	8 (17.8%)	
MI prevalence			
No	20 (90.9%)	24 (53.3%)	0.006 *
Yes	2 (9.1%)	21 (46.7%)	
Participants (n)	22 (32.8%)	45 (67.2%)	-
MI cases	2 (5,9%)	32 (94,1%)	-
Injury/gymnast	0.09	0.71	
Injury/injured gymnast	1.0	1.52	-

BMI, body mass index; MI, musculoskeletal injuries; G1, participants in remote training; G2, participants in face-to-face training. [a] Quantitative variables presented in mean ± SD and analyzed using Student t-test; [b] quantitative variables presented in median and interquartile interval and analyzed using Mann-Whitney test. Gender and MI prevalence analyzed with Chi-square test. * p<0.05.

Table 2
Postural balance analysis according to group and lower limb side

Variable	Group	Lower Limb (Side)		p-value		
		Dominant	Non-Dominant	Group	Side	Interaction
AP Sway (cm)	G1	4.58 ± 1.42	5.31 ± 2.14 #	0.012*	0.106	0.050 †
	G2	3.55 ± 2.13 *	3.50 ± 2.00 *			
ML Sway (cm)	G1	3.35 ± 0.66	4.24 ± 3.90	0.011*	0.097	0.240
	G2	2.55 ± 1.38	2.60 ± 1.44			
Area (cm²)	G1	10.11 ± 5.86	10.28 ± 4.65	<0.001*	1.000	1.000
	G2	7.13 ± 5.49	7.31 ± 5.09			
API Speed (cm/s)	G1	4.19 ± 1.15	4.30 ± 1.40	0.013*	0.532	0.845
	G2	3.29 ± 2.00	3.29 ± 1.91			
MLI Speed (cm/s)	G1	4.21 ± 1.15	4.33 ± 1.28	0.020*	0.580	0.566
	G2	3.40 ± 1.91	3.41 ± 1.88			

AP, anteroposterior; ML, mediolateral; API Speed, anteroposterior imbalance speed; MLI Speed, mediolateral imbalance speed. Results expressed in mean ± standard deviation; * p<0.05, group's effect; #p<0.05, lower limb side effect; † p<0.05, interaction's effect. Two-Way RM ANOVA and Bonferroni's test.

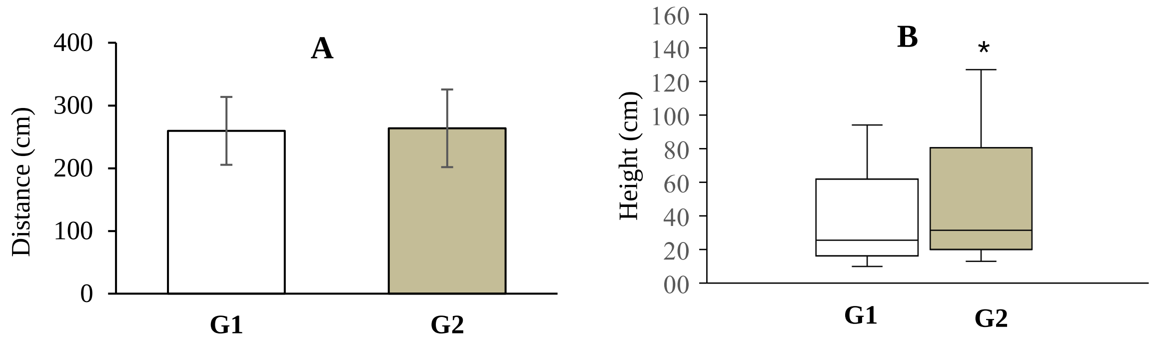

Figure 1. (A) Mean and standard deviation of upper limbs reaching performance, according to group; G1, participants in remote training; G2, participants in face-to-face training; Student-t test (p>0.05). (B) Descriptive measures of lower limbs performance; * p<0.05 vs. G1; Mann-Whitney test.

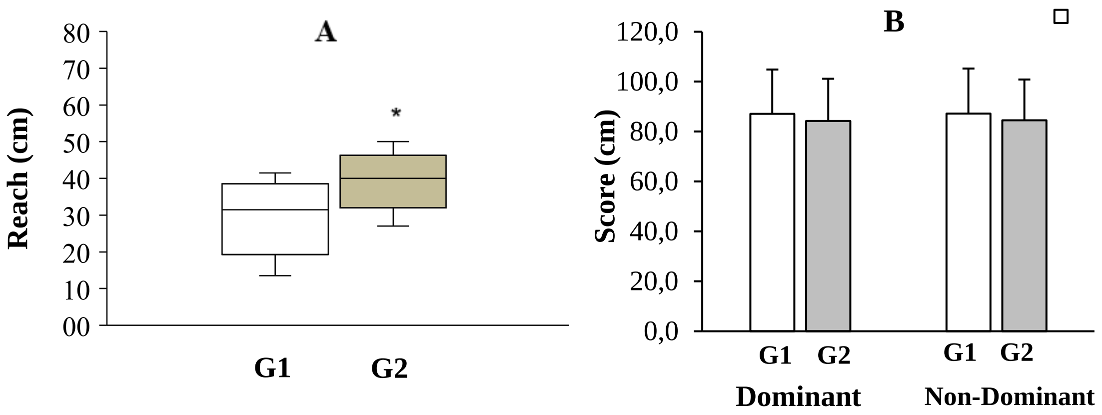

Figure 2. (A) Descriptive measures of muscle flexibility according to group; G1, participants in remote training; G2, participants in face-to-face training; * p<0.05 vs. G1; Mann-Whitney test. (B) Mean and standard deviation of dynamic balance according to group and lower limb side (p>0.05); Two-way RM ANOVA and Bonferroni's test.

Table 3
Musculoskeletal injuries prevalence according to anatomical site, onset circumstance, mechanism, and number of cases

Variables	Prevalence		p-value
	Absolute (n)	Relative (%)	
Anatomical site			
Lower limbs	20	58.8%	0.508
Other	14	41.2%	
Total (cases)	34		
Onset circumstance			
Floor exercises	28	82.4%	0.007 *
Other	6	17.6%	
Total (cases)	34		
Number of MI cases			
1 retrospective case	15	65.2%	0.340
2-3 retrospective cases	8	34.8%	
Total (participants)	23		

Z-test comparison of proportions; * p<0.05.

Based on associated characteristics and MI records, Table 4 presents numerical data related to probability models for four different outcomes: retrospective MI onset, MI in lower limbs, MI from floor exercises, and MI recurrence.

Firstly, the time of practice, dynamic balance (non-dominant lower limb), and training condition (face-to-face) were directly associated with the chances of MI onset. Conversely, SEBT (dominant lower limb) was negatively associated with MI risk, showing a 25% increased chance of MI onset. Face-to-face training conditions were associated with at least a 10-fold increase in MI onset risk. The ROC curve for this model showed an AUC value of 0.897, with an optimal cut-off value of 0.351, corresponding to a specificity of 0.795 and a sensitivity of 0.913 (Figure 3A).

For MI cases in lower limbs, time of practice (experience) and flexibility were directly associated with an increased risk of MI onset in lower limb sites. Increases in these variables were linked to a higher risk of MI among gymnasts. Dynamic balance (dominant lower limb) was associated with an 8.7% increased risk of lower limb MI onset. The ROC curve for this model had an AUC value of 0.836, with an optimal cut-off value of 0.231, resulting in a specificity of 0.740 and a sensitivity of 0.882 (Figure 3B).

Table 4
Model of probability to musculoskeletal sports injury (MI) onset prediction

Outcome	Variable	Coefficient	SE	p-value	OR	CI (95%)
Sports Injury	Constant	-0.71	2.07	0.73		
	Time of practice (years)	0.72	0.25	<0.01	2.05	1.32 – 3.53
	SEBT (dominant)	-0.23	0.08	<0.01	0.80	0.66 – 0.90
	SEBT (non-dominant)	0.18	0.07	0.01	1.20	1.08 – 1.42
	Training (face-to-face)	2.33	1.00	0.02	10.25	1.78 – 101.89
LL cases	Constant	-0.99	2.26	0.66		
	Time of practice (years)	0.36	0.18	0.05	1.43	1.02 – 2.14
	SEBT (dominant)	-0.08	0.03	<0.01	0.92	0.86 – 0.97
	Flexibility	0.15	0.06	0.01	1.16	1.04 – 1.33
Floor (cases)	Constant	-0.04	2.11	0.99		
	Age category	0.76	0.26	<0.01	2.15	1.37 – 3.82
	SEBT (dominant)	-0.22	0.07	<0.01	0.81	0.68 – 0.91
	SEBT (non-dominant)	0.16	0.06	0.01	1.17	1.06 – 1.35
	Training (face-to-face)	2.59	1.04	0.01	13.27	2.19 – 149.82
Rec	Constant	-8.66	3.31	0.01		
	Flexibility	0.17	0.08	0.03	1.19	1.01 – 1.39

SE, standard error; OR, odds ratio; CI, confidence interval; SEBT, star excursion balance test; Training condition: 0, remote; 1, face-to-face; LL cases, lower limbs MI cases; WTT, week training time; Rec., MI recurrence.

Age, dynamic balance (non-dominant lower limb), and training condition were directly associated with sports injuries resulting from floor exercises. Face-to-face training conditions were linked to approximately a 13-fold increase in the risk of MI onset from floor exercises. A reduction in dynamic balance of the dominant leg was associated with a 23.4% increased risk of MI onset during floor exercises. The ROC curve for this model had an AUC value of 0.895, with an optimal cut-off value of 0.285, resulting in a specificity of 0.759 and a sensitivity of 0.909 (Figure 3C).

The MI recurrence prediction model indicated that flexibility was directly associated with increased chances of MI recurrence (p=0.03). The ROC curve for this model showed an AUC of 0.770 and an optimal cut-off value of 0.111, with specificity and sensitivity values of 0.627 and 0.875, respectively (Figure 3D).

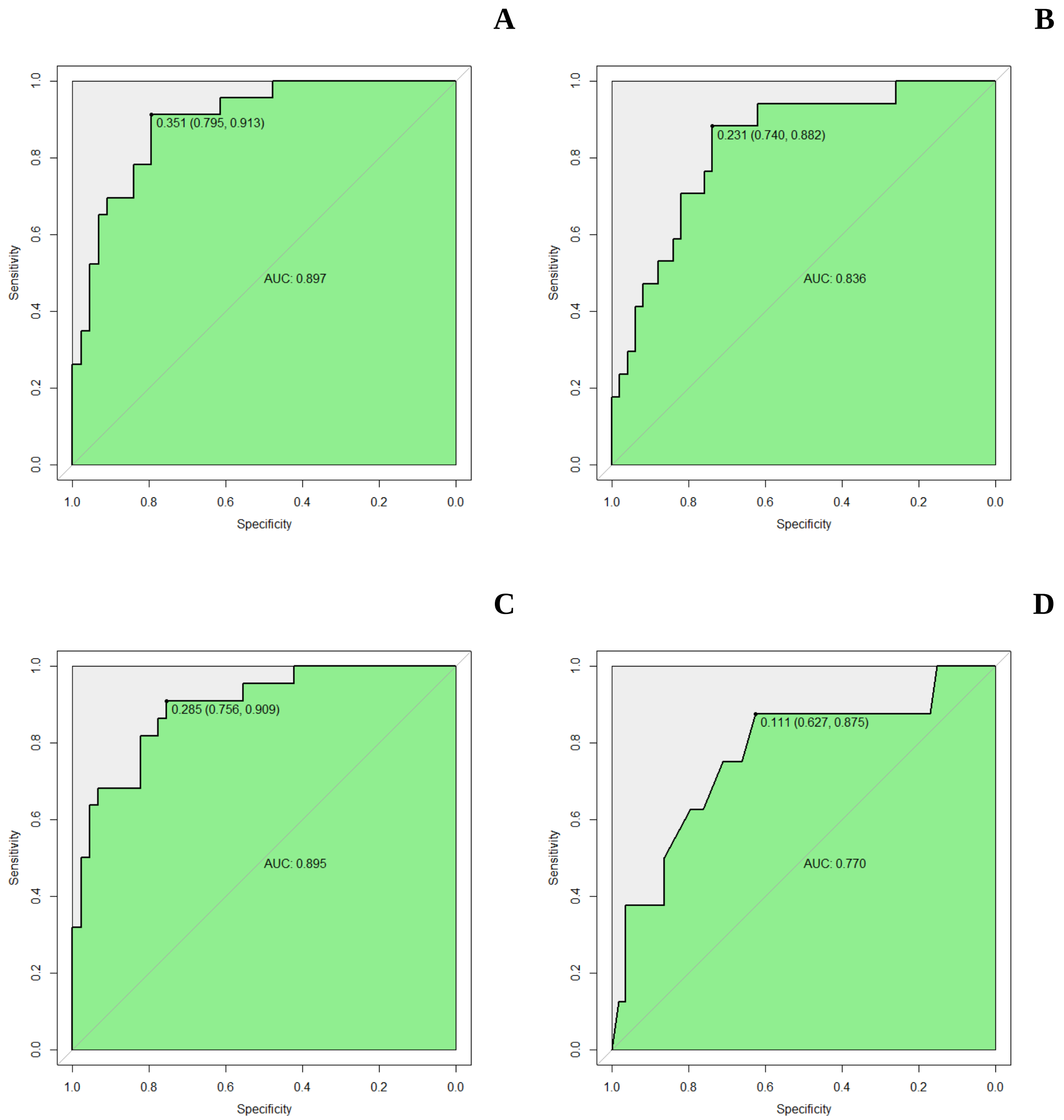

Figure 3. ROC curve for the (A) sports injury onset; (B) lower limb sports injury; (C) sports injury associated with floor exercises; and (D) sports injury recurrence. AUC, area under curve obtained from respective sensitivity and specificity values.

DISCUSSION

This study aimed to analyze the association between different training routines and performance parameters, as well as the prevalence of musculoskeletal injuries (MI) in young gymnasts following the onset of the COVID-19 pandemic. The initial hypothesis posited that remote training schedules were associated with lower performance levels and a higher prevalence of sports injuries in gymnasts.

The COVID-19 pandemic led to significant adaptive changes in training schedules and routines. Specifically, face-to-face training was associated with improvements in performance, including greater muscle power, flexibility, and postural stability, compared to remote training. These findings not only support the initial hypothesis but also confirm that COVID-19 lockdowns had a detrimental impact on training practices and coaching-related aspects. Remote training schedules were linked to reduced training exposure and overload, which contributed to a significant decline in performance, as supported by previous evidence (Jagim et al., 2020; Patel et al., 2022; Washif et al., 2022).

Regular AG training is associated with improvements in power, speed, balance, and muscle flexibility, as demonstrated by the results from the G2 subjects. Muscle flexibility development, in particular, is a common outcome of AG training, linked to a greater range of motion and enhanced muscle power (Moeskops et al., 2019; Root et al., 2019). Lima et al. (2019) compared the effects of two stretching interventions, non-periodized versus periodized, on gymnasts' motor skills and found that periodized training significantly increased muscle flexibility and performance scores.

Regarding postural balance, gymnastics experience may enhance proprioceptive balance in young athletes (Busquets et al., 2018). A systematic review with meta-analysis by Gebel et al. (2018) assessed the effects of balance training (static vs. dynamic interventions) on measures of static and dynamic balance in healthy children and adolescents. The review concluded that regular balance training improves balance performance with moderate to large effects on both static and dynamic balance, regardless of age, sex, training status, setting, and testing method. Our balance results (Table 2) align with this background, showing that higher training scores (G2) were associated with improved performance and static balance control.

Advanced motor skill levels are important for enhancing physical, social, and psychological characteristics in children and adolescents (Kirialanis et al., 2015). However, results from the star excursion balance test indicate that different AG training conditions did not lead to specific changes in dynamic balance biomechanical adaptations. The imprecise control of workload during the retrospective period may have contributed to the lack of substantial impact on dynamic balance.

Regarding the prevalence of musculoskeletal injuries, a total of 23 participants (34.3%) reported at least one case of retrospective sports injury during the training period following the COVID-19 pandemic onset (2020 to 2021). Face-to-face training routines were associated with increased exposure to training overloads, which may constitute an extrinsic factor related to the onset of sports injuries (Boullosa et al., 2020; Root et al., 2019). Other studies have reported similar training characteristics between uninjured and injured competitive participants (Hoshi et al., 2008).

Our investigation involved a high number of young participants classified as competitive and "non-elite," according to previous definitions (Ling et al., 2020). These gymnasts are generally exposed to greater demands in learning training elements and developing basic physical abilities. Consequently, a focus on lower limb exercises, as opposed to upper limb exercises, is common in these situations (Šarabon & Čeklić, 2021), which may be associated with various biomechanical effects.

Historically, previous MIs have been known to impact dynamic balance, with lower limb injuries in AG becoming increasingly prevalent (Dallas et al., 2017; Kirialanis et al., 2015). Lower limb sites were the most commonly reported locations for MI in this study, often accompanied by residual symptoms such as pain, impaired proprioception, and reduced neuromuscular control (Dallas & Dallas, 2016). Research has shown that differences in performance between lower limb sides can increase the probability of sports injuries (Plisky et al., 2006).

In this study, logistic regression models indicated that reduced dynamic balance in the non-dominant lower limb was associated with a higher likelihood of MI onset, both in general and specifically from floor exercises. The ROC curves for these models demonstrated satisfactory predictive performance. These findings suggest that non-dominant limbs play a crucial role in maintaining functional stability. However, the observed differences in dynamic balance measures were minimal and may not significantly impact the results of the Star Excursion Balance Test (SEBT).

Besides biomechanical factors, face-to-face training conditions and time of practice were the main characteristics associated with the onset of MIs)(Table 4). Understanding the potential causes of sports injuries requires a multifactorial approach that considers the interactions among various conditions and both modifiable and non-modifiable risk factors (Bahr & Krosshaug, 2005).

The COVID-19 pandemic led to varying levels of mobility restrictions, interrupting face-to-face training across multiple sports modalities and replacing it with remote activities. These remote activities were often marked by inadequate monitoring and load management, as well as lower adherence (Wang et al., 2021). The reduced and less specific stimuli from these remote training sessions could impair performance development and conditioning, increasing the risk of injury due to the accumulation of workload during subsequent sports activities (Boullosa et al., 2020). The progressive return to regular face-to-face training, coupled with a denser competitive calendar in 2021, likely contributed to a higher odds ratio for MI onset.

The training schedule was directly associated with the onset of lower limb injuries and cases derived from floor exercises (Table 4). These associations were supported by high sensitivity and specificity in the ROC curve analyses (Figure 3). Face-to-face training activities often involve repetitive practices and overloads, with significant demands on the lower limbs due to floor movements. Other studies have identified floor exercises as a primary context for MI onset in AG athletes, linked to increased exposure and overload during floor training (Campbell et al., 2019).

Floor exercises involve high-impact activities, particularly during the landing phase of jumps, which is when many gymnastics injuries occur (Kirialanis et al., 2015). Training at an advanced competitive level and performing in competitions exacerbate the risks associated with floor exercises (Campbell et al., 2019). Additionally, flexibility was directly associated with lower limb injuries and the recurrence of MIs. Flexibility improvements are commonly achieved through regular AG training, and extended practice time promotes this adaptation (Mkaouer et al., 2018). However, from a biomechanical perspective, increased training volume during face-to-face activities may enhance movement specificity but also result in greater flexibility. Over time, this can negatively affect muscle strength and power, potentially leading to injury onset and recurrence of MIs (Sweeney et al., 2019).

Understanding musculoskeletal injuries and their associated factors is crucial for developing effective preventive and rehabilitation strategies in sports. The findings of this study are valuable for athletes, coaches, physiotherapists, and parents concerned with the performance and health of young athletes. Previous research has highlighted differences in workload management between individual and team sports, suggesting that individualized periodization in team sports can improve fitness-fatigue balance, reduce injury risk, and enhance performance (Boullosa et al., 2020).

In this context, the results of the current study underscore the importance of workload management in artistic gymnastics—not only for injury prevention but also for performance monitoring. This has practical implications for training regimens. However, a limitation of this study is the potential for high recall bias regarding the occurrence and characteristics of injuries, as reported by adolescents (Vanderlei et al., 2017). Future studies with a prospective follow-up design are more likely to identify causal relationships and better understand the onset of musculoskeletal injuries.

CONCLUSION

In conclusion, while face-to-face training regular routine was associated with greater performance, it resulted in higher MI prevalence. Lower limbs were the main injured anatomical sites, and exercises on the floor constituted the main circumstances for injury onset.

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EPIDEMIOLOGY OF INJURIES AND ASSOCIATED RISK FACTORS IN ATHLETES PARTICIPATING IN 2022 AEROBIC GYMNASTICS WORLD CHAMPIONSHIP

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Abstract
Exercise is described as a preventive and therapeutic strategy against various diseases. However, competitive sports practice is associated with an increased risk of injuries, particularly with specialization and more intense training at younger ages. Given the importance of surveillance and epidemiological studies to protect athletes' health, our study aimed to describe the prevalence of injuries among athletes at the 2022 Aerobic Gymnastics World Championship (WCH) and to understand the intrinsic and extrinsic risk factors that may contribute to these injuries. Athletes participating in WCH 2022 were invited to complete a retrospective injury questionnaire covering the past 12 months of their training schedule. Descriptive statistic data were used to analyze all variables in the study. Seventy-three percent of athletes reported sustaining injuries, with an average of 1.6 ± 1.5 injuries occurring one to three times in the past year. The most common injuries were muscle injuries, joint sprains, stress fractures, and contusions, with the lower limbs being the most affected, followed by the upper body and trunk. Regarding injury risk factors, a significant number of athletes reported experiencing psychological stress (p=0.043) and concerns about individual protection equipment (p=0.042). Given that the type of injury and affected body region seem to be related to sports-specific movements, the impact absorption of the floor and footwear should be studied further. Additionally, injury prevention measures should include coping strategies to manage stress effectively.

Keywords: *sport; traumatology; competition; elite.*

INTRODUCTION

According to the "Extreme Exercise Hypothesis," increasing exercise volume leads to a curvilinear decrease in health risks, with the benefits being partially lost when exercise exceeds the optimal dose (Eijsvogels, Thompson, and Franklin 2018). However, this theory was recently challenged by Runacres et al. (2021), who demonstrated that athletes tend to live longer and have a reduced incidence of cardiovascular and cancer mortality compared to the general population. While athletes' health outcomes and life expectancy are not compromised by training volume and intensity, the increased exposure time during practice and competition does lead to a higher occurrence of injuries (Caparrós et al. 2016).

Among top-level athletes, injuries not only hinder sports performance but are also recognized as a risk factor for psychological distress (Haugen 2022) and are a major cause of premature career termination (Arundale, Silvers-Granelli, and Snyder-Mackler 2018; Ristolainen et al. 2012). Moreover, some athletes do not fully recover after an injury, which can lead to repeated trauma in the same area and, subsequently, a more severe condition (Bitchell et al. 2020). In gymnastics, acute injuries tend to increase with the risk and challenges of the exercises, while chronic injuries are often associated with skill level development and increased workout load (Meeusen and Borms 1992).

Studies on intrinsic factors in aerobic gymnastics (AER) report that height, weight, and age are associated with an increased risk of injury, while performance level and sport equipment (such as the floor) are suggested as important extrinsic factors (Caine and Nassar 2005). The first epidemiological study in Aerobic Gymnastics (AG) was conducted by Navarro et al. (2003), followed by the study of Fetterplace (2004). Fetterplace found 61 injuries among senior gymnasts participating in the Federation of International Sports, Aerobics, and Fitness competition, with the lower limbs being the most affected (52.4%), particularly the ankle/foot (29.5%), wrist (13.1%), and lower part of the thigh (13.1%). Later, Navarro et al. (2004) showed that muscle injuries are the most frequent, followed by joint and bone tissue injuries. Regarding risk factors, Navarro et al. (2005) reported a high percentage of injuries (88%) among athletes who did not use adequate floor, particularly during jumps and jumps involving falls with bracing arms and splits. Although protective materials may reduce the occurrence of these injuries, Abalo and Gutiérrez (2009) found that their use is not very popular among AG athletes. In line with the International Olympic Committee's (2020) stance that injury epidemiological studies are essential for protecting athletes, collected data provide the basis for developing injury prevention programs. Based on this concern, international federations and research centers have applied injury surveillance in major events (for references, see Soligard et al. 2017). However, to the best of our knowledge, only one study has addressed this issue in adult world top-level AG athletes (Fetterplace 2004).

Therefore, we aimed to describe the prevalence of injuries among athletes at the 2022 Aerobic Gymnastics World Championship (WCH) and to understand the related intrinsic and extrinsic risk factors. This information will be an important tool for developing specific injury prevention plans and programs for this sport. Based on previous studies, we hypothesize that top-level aerobic gymnastics athletes will report a large number of acute and chronic injuries in the lower extremities (Fetterplace 2004), particularly affecting muscle tissue (Navarro et al. 2004), due to factors such as anthropometrics, age, floor characteristics, and protection equipment (Caine and Nassar 2005; Navarro et al. 2005).

METHODS

All male and female gymnasts who participated in the 2022 Aerobic Gymnastics World Championship were eligible to complete the survey. Out of a total of 259 athletes from 32 countries, 189 agreed to answer the questionnaire. Therefore, sample selection was performed through an auto-selection method. Participants were excluded if they were under 18 years old at the time of the competition or did not confirm their informed consent. The inclusion criteria defined athletes who participated in the 2022 Aerobic Gymnastics World Championship.

The cross-sectional research design was previously approved by the Anti-Doping, Medical, and Mental Health Commission of the Fédération Internationale de Gymnastique (FIG). An email was sent to all delegations one month before the competition, outlining the research aims and procedures. The injury questionnaire and data collection process were structured based on retrospective designs for Sports Injury Surveillance Studies (Mukherjee 2015) and previous studies (Fuller et al. 2006; International Olympic Committee Injury and Illness Epidemiology Consensus Group et al. 2020; Prieto-González et al. 2021).

The instrument comprised 29 close-ended and open-ended questions, available in three languages (Portuguese, Spanish, and English), and was divided into three sections:

1. *Sample data:* This section included questions about age, sex, body weight, and height.
2. *Injury-related intrinsic and extrinsic risk factors:* This section focused on sport-specific data, such as aerobic gymnastics experience (years), training sessions per week, number of competitions, categories, and various questions related to training and competition risk factors.
3. *Injury characterization:* Athletes who reported injuries continued to answer questions about the number and type of injuries suffered in the last 12 months, the body region affected, and the mechanism of injury (e.g., acute/chronic, during training/competition, alone/collision).

Athletes' responses were collected using Survio Software, accessible on various electronic devices (tablets, computers, and phones). All data was anonymous and confidential, and Survio Software adheres to privacy protection regulations, as detailed at https://www.survio.com/en/privacy-policy. During the data collection process, research team members were present to ensure the completeness and accuracy of all fields, to clarify any doubts, and to enhance participation rates and the validity of responses (Mukherjee 2015). Additionally, the questionnaires were administered during training sessions at the sport event facilities, after podium training, to avoid psychological stress related to the competition.

The sample size was calculated with a 5% margin of error and a 99% confidence interval from a population of 314 athletes, establishing a minimum required size of 187 subjects. Descriptive statistical analysis was conducted for all study variables using SPSS software (version 28.0). The dependent variables included injury characteristics (e.g., number, type, body part affected, mechanisms) during the 2021-2022 season, while the independent variables encompassed sample data (age and sex) and internal and external risk factors (e.g., training experience, safety equipment, training equipment and facilities, nutrition, stress). Data were organized and presented in frequency distributions, and Pearson's correlation was performed to test the relationships between risk factors and the presence or absence of injuries.

RESULTS

A total of 189 athletes from the World Aerobic Gymnastics Championship (WCH) completed the questionnaire and met all inclusion criteria. The respondents were predominantly female (n=139), with average age of 21.2 years as seen in Table 1.

Sport-specific data (Table 2) show that aerobic gymnasts typically begin their practice between the ages of 6 and 13 years. On average, their training schedules include six sessions per week, each lasting approximately three hours, totaling about 17.9 to 16.5 hours per week. During the 2022 competition season, these athletes participated in an average of six competitions and competed in more than one category (2.6 ± 1.1 and 2.6 ± 1.3 categories, respectively).

Table 1.
Characterization of 2022 Aerobic Gymnastics WCH athletes (n=189)

Parameters	
Sex % (n)	
Female	73.5% (139)
Male	26.5 % (50)
Age, years (Mean ± SD)	21.2 ± 4.1
Height, cm (Mean ± SD)	165.6 ± 8.2
Weight, Kg (Mean ± SD)	59.1 ± 8.6

Table 2.
Injury risk-factors reported by injured or not-injured athletes that participated in the 2022 Aerobic Gymnastics WCH

Risk Factors	**Athletes with Injuries (Mean ± SD)**		**Athletes without Injuries (Mean ± SD)**	
Years of AG practice	11.1 ± 5.2		12.3 ± 4.9	
Age of time of specialization	9.9 ± 3.9		8.4 ± 3.5	
Frequency (nº/week)	5.9 ± 1.7		6.3 ± 2.2	
Duration (hours/week)	17.9 ± 10.4		16.5 ± 5.3	
Competitions (2022 season)	6.2 ± 2.9		5.9 ± 2,5	
Number Categories (2022 season)	2.6 ± 1.1		2.6 ± 1.3	
	Yes, % (*N*)	**No, % (*N*)**	**Yes, %(*N*)**	**No, % (*N*)**
Individual Strength Conditioning	86.0 (104)	14.0 (17)	91.3 (42)	8.7 (4)
Exercises to Prevent Injuries	95.9 (116)	4.1 (5)	91.3 (42)	8.7 (4)
Warm Up	100 (121)	0 (0)	97.8 (45)	2.2 (1)
Cool-Down	89.3 (108)	10.7 (13)	82.6 (38)	17.4 (8)
Individual Protection[a]	91.7 (111)	8.3 (10)	73.9 (34)	26.1 (12)
Good Sport Facilities Equipment's	81.8 (99)	18.2 (22)	91.3 (42)	8.7 (4)
Good Sport Facilities	65.3 (79)	34.7 (42)	73.9 (34)	26.1 (12)
Training Load adapted to athletes	87.6 (106)	12.4 (15)	93.5 (43)	6.5 (3)
Individual balance diet	69.4 (84)	30.6 (37)	69.6 (32)	30.4 (14)
Psychologic Stress[b]	54.5 (66)	45.5 (55)	37.0 (17)	63.0 (29)
Recurrent injuries	57.9 (70)	38.8 (47)	0 (0)	0 (0)
Other sport practice	14.9 (18)	85.1 (103)	17.4 (8)	82.6 (38)

[a]vs. with and without injuries, p= 0.002
[b]vs. with and without Injuries, p= 0.043

Injury Risk Factors**:** Both injured and non-injured athletes reported experiencing psychological stress ($p = 0.043$) and noted the use of individual protection equipment ($p = 0.002$). Nearly all athletes performed warm-up and cool-down routines, engaged in individualized strength conditioning, and practiced exercises designed to prevent injuries. Additionally, respondents reported having good training conditions, including adequate facilities, equipment, and manageable training loads.

Seventy-three percent of athletes (n=121/167) reported sustaining injuries one to three times (1.6 ± 1.5) in the past 12 months (Table 3). Injuries affected various tissues, with muscle injuries and ligament injuries being the most commonly reported (85.8% and 69.2%, respectively). Muscle injuries (including strains, tears, and ruptures) and joint sprains were most frequent. These injuries predominantly occurred acutely (42.7%), during training (74.6%), and without collision (80.9%) (Table 4).

Lower extremities were the most affected by injuries, followed by upper body and trunk regions (Figure 1). Among the lower body injuries, the ankle, knee, and foot were most frequently reported. In the upper extremities, the shoulder, wrist, and hand were commonly affected. In the trunk region, injuries were mainly reported in the hip and lumbar spine

Table 3.
Characterization of 2022 Aerobic Gymnastics WCH athletes' injuries

Injured athletes % (n)	72,3% (121)
Injured Number (Mean ± SD)	1.6 ± 1.5
Tissue/ Injury type (%)	
Muscle/Tendon (n = 132)	
Muscle injury	85.8 %
Muscle contusion	19.8%
Muscle compartment syndrome	6.6%
Tendinopathy	44.9%
Tendon rupture	17.2%
Nervous (n = 25)	
Brain/spinal cord injury	48.0%
Peripheral nerve injury	52.0%
Bone (n = 40)	
Fracture	17.5%
Bone stress injury	47.5%
Bone contusion	35.0%
Cartilage/Synovium/Bursa (n = 46)	
Cartilage injury	28.3%
Arthritis	21.7%
Synovitis/Capsulitis	21.7%
Bursitis	28.3%
Ligament/Joint capsule (n = 65)	
Join Sprain (ligaments tear or acute instability episode)	69.2%
Chronic instability	30.8%
Superficial tissues/Skin (n = 43)	
Contusion (superficial)	53.5%
Laceration	14.0%
Abrasion	32.6%

Table 4.
Mechanisms o of 2022 Aerobic Gymnastics WCH athletes' injuries

Mechanism of Injury	
Load type (n = 96)	
Acute	42.7%
Overuse	34.4%
Acute and overuse	22.9%
Place (n = 110)	
Training	74.6%
Competition	4.2%
Training and Competition	21.2%
Contact (n = 121)	
Alone	80.9%
With another athlete	10%
With an object	9.1%

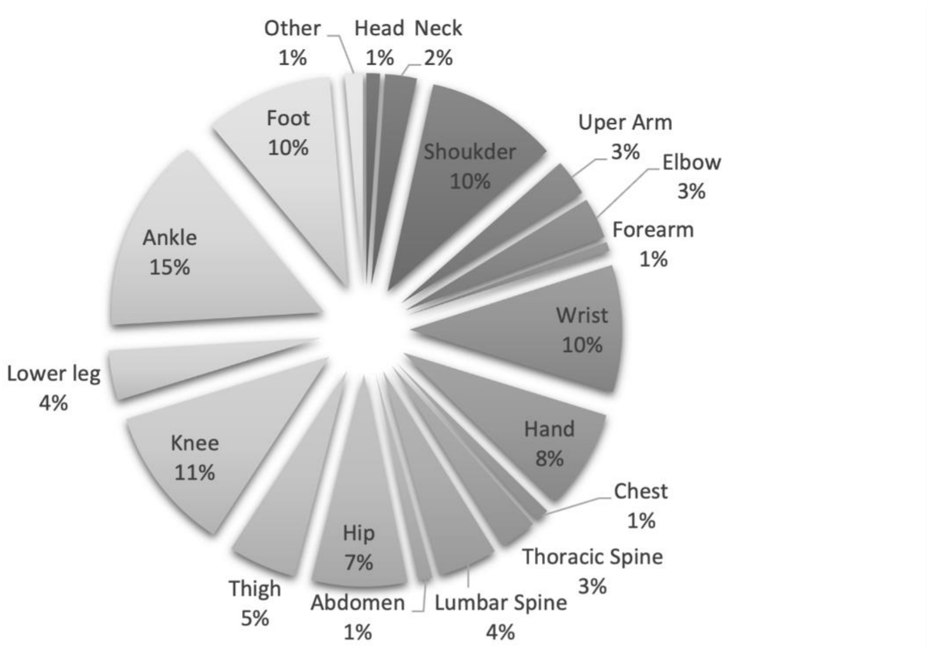

Figure 1. Number of body parts injured reported by athletes in the 2022 Aerobic Gymnastics WCH

DISCUSSION

In AG, athletes must demonstrate high levels of strength, endurance, and flexibility during demanding choreography that requires coordination and speed (Abalo, Gutiérrez-Sánchez, & Vernetta, 2013). High-impact exercises and the use of aerobic equipment, such as floors and footwear, have been suggested as potential contributors to increased injury rates, particularly in the lower limbs (Abalo et al., 2013). According to our questionnaire, more than seventy percent of athletes reported injuries in the past 12 months, with over fifty percent of these being recurrent. Previous studies have shown that gymnasts often resume practice before fully recovering or continue to train and compete despite ongoing symptoms (Caine et al., 1989; Harringe, Renström, & Werner, 2007; Kolt & Kirkby, 1999; Sands, Shultz, & Newman, 1993), which may explain the observed results.

Among the risk factors, we found that 54.5% of injured athletes experienced psychological stress from coaches, friends, family, or themselves. Since stress and anxiety can influence the risk, frequency, and severity of injuries (Pal, Kalra, & Awasthi, 2021), coping strategies are crucial for protecting athletes. Additionally, life-related stress should be considered in preventive programs, as it is a significant predictor of injury in non-elite gymnasts (Kolt & Kirkby, 1999). Thus, both injury history and stress factors (including major life events and previous injuries) should be incorporated into surveillance systems and preventive measures for top-level AG athletes.

Beyond physical and psychological health, nutrition plays a crucial role in both injury risk and the recovery process (Smith-Ryan et al., 2020). Dietary recommendations include: i) identifying individual caloric requirements; ii) increasing protein intake to prevent muscle loss and maintain strength during immobilization; and iii) using supplements to address caloric intake and nutrient deficiencies (Close et al., 2019). Top-level gymnasts are particularly at risk for eating disorders due to the sport's aesthetic demands and rigorous training sessions (Silva & Paiva, 2015; Tan et al., 2016). Our results show that 30% of aerobic gymnasts still do not follow a balanced diet, highlighting the need for nutritional education to promote healthier eating choices.

Additionally, while the use of individual protective equipment was reported by many injured athletes, suggesting an increased concern for injury prevention, it remains crucial to address other factors. As noted in previous studies (Abalo & Gutiérrez, 2009), injury processes were predominantly traumatic and occurred during training. Therefore, the condition of sport facilities, such as the floor, should be scrutinized. Our findings support earlier theories of a higher incidence of lower limb injuries, followed by upper extremities (Fetterplace, 2004; Navarro et al., 2005), due to the impact absorption demands (Navarro et al., 2004). Despite changes in the AG Code of Points over the years, muscle injuries, tendinopathies, joint sprains, stress fractures, and contusions affecting the ankle, foot, knee, wrist, and shoulder remain prevalent. This suggests that these injuries are closely related to the fundamental movements of the sport.

To develop and implement effective injury prevention programs, a four-step framework that identifies the injury problem and its etiology has been proposed (Van Tiggelen et al., 2008). Our study aimed to update trends in injury and associated risk factors among elite AG athletes, which may assist technical and medical teams in establishing measures to prevent injuries, thereby improving performance and extending athletes' careers.

In the current study, we observed that the type and location of injuries appear to be related to specific sports movements. Psychological stress and the use of individual protective equipment were identified as major risk factors. Consequently, preventive intervention programs should incorporate coping strategies to manage stress and examine the impact of floor and sport footwear on injury risk to improve impact absorption. Additionally, with artificial intelligence emerging as a promising methodology for identifying athletes at high risk of injury and detecting risk factors (Van Eetvelde et al., 2021), future studies in AG should consider integrating this technology.

CONCLUSION

The current study offers new insights into injury patterns and risk factors among elite world AG athletes. Our findings reveal that acute injuries, such as muscle strains and joint sprains, remain common in this sport. These injuries may be attributed to sport-specific movements and equipment. Additionally, psychological stress is frequently reported among elite gymnasts, alongside concerns regarding individual protection measures. Therefore, future studies should focus on the development of AG equipment, psychological support, and comprehensive recovery strategies for injured athletes.

LIMITATIONS

The survey mode presents limitations due to auto-selection bias, which may affect the representativeness of the sample relative to the target population. Additionally, memory recall bias is a concern, as retrospective injury studies rely on self-reported data based on athletes' recollections. This could lead to an underestimation of injury incidence, as athletes might predominantly recall more significant injuries while overlooking less severe ones.

Disclosure Statement
The authors report no conflict of interest

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THE EFFECTS OF 12 WEEKS BASIC GYMNASTICS EXERCISES ON BODY COMPOSITION AND LIPID PROFILES IN OBESE CHILDREN

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Abstract

Obesity is a major health concern in the world because it is associated with many diseases. It has been shown that basic gymnastics exercises effectively prevent and treat this problem. Therefore, the present study investigated the effect of 12 weeks of basic gymnastics exercises on body composition and lipid profile in obese girls. In this quasi-experimental study, with a design pre-test-post-test and a control group, 30 obese girls with Body Mass Index (BMI) at or above the 95th percentile and the average age of 9.4 years, were selected purposefully and were divided into 2 groups (Basic gymnastics training, and control) randomly. The training protocol was implemented for 12 weeks, three times a week, and 45 minutes for each session incrementally. Body composition and lipid profile indices were measured in two stages: pre-test and post-test. In order to analyze the data, multivariate covariance tests were used.

The results of the study showed that the exercise intervention significantly reduced the fat percentage and BMI index in obese children ($p \leq 0.001$). In addition, a significant decrease in total cholesterol, triglyceride, and Low Density Lipoprotein Cholesterol (LDL-C) and a significant increase in High Density Lipoprotein Cholesterol (HDL-C) were observed ($p \leq 0.002$). These findings indicate the beneficial effects of basic gymnastics training on body composition and lipid profile in obese children. Therefore, the use of basic gymnastics training is recommended to improve these factors.

Keywords: *Body composition, Basic gymnastics Training, Lipid profile, Obese girls.*

INTRODUCTION

Obesity and overweight in childhood is one of the most important public health problems worldwide. It is estimated that over 330 million children aged 5-19 years suffer from severe malnutrition (Yamamoto, 2021). According to the Center for Disease Control and Prevention (CDC), 4 out of 10 Americans are currently obese. Additionally, the World Obesity Federation predicts that by 2030, one in five women and one in seven men will be obese (Memelink et al., 2023). Specifically, 12.7 % of children aged 2 to 5 years, 20.7 % of those aged 6 to 11 years, and 22.2 % of adolescents aged 12 to 19 years in the United States are obese. Worldwide, more than 340 million children and adolescents between the ages of 5 to 19 years, and 39 million children under 5 years old, are considered obese (Sanyaolu et al., 2019).

In Iran, a meta-analysis conducted from January 2000 to January 2021 examined 2,637,912 children and adolescents aged 2 to 15 years. The overall prevalence of obesity in this group was found to be 11.4% (95% confidence interval: 9.4-13.7%) (Akbari and Mohammadi, 2022). The rising rates of childhood obesity are accompanied by an increase in non-communicable chronic diseases at younger ages, including dyslipidemia, hypertension, nonalcoholic fatty liver disease, obstructive sleep apnea, type 2 diabetes, certain cancers, heart disease, and psychosocial disorders (Leung et al., 2024). According to the World Health Organization (WHO), obesity contributes to four million deaths annually (Jebeile et al., 2022).

Childhood and adolescent obesity have detrimental effects on metabolism that can significantly reduce a person's lifespan. The increase in childhood obesity is driven by various factors, including genetics, hormonal imbalances, metabolic issues, behavioral and nutritional factors, and, ultimately, an imbalance between energy intake and expenditure, coupled with a reduction in physical activity (Walls et al., 2009). The development and persistence of obesity are largely influenced by a biosocial framework, where biological predispositions interact with socioeconomic and environmental factors to promote adipose tissue proliferation and obesity. First-line therapeutic approaches often involve family-based interventions aimed at promoting effective behavioral changes in diet, physical activity, avoidance of sedentary behaviors, and improvement in sleep quality.

However, there is emerging evidence supporting more intensive interventions, such as nutritional supplementation, pharmacotherapy, and metabolic surgery, as adjunctive therapies. Unfortunately, access to these treatments remains limited in many communities (Jebeile et al., 2022).

It is crucial to treat childhood obesity early to manage it before complications arise. Diet modification, exercise therapy, behavior modification, and preventive activities are the foundational principles of treatment. However, children with obesity have limited access to effective treatments compared to adults, as drug therapy and other treatment studies often do not include children.

Moreover, families and medical providers are frequently hesitant to implement these interventions in children due to potential risks or side effects associated with drug and medical treatments (Leung et al., 2024). Given this, it appears that the first line of prevention and treatment for overweight and obesity should be the implementation of physical and sports activities.

Total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglycerides (TG) are among the most critical components of blood lipids related to health. Numerous studies have shown that exercise training interventions reduce body fat and improve lipid profiles, thereby lowering the risk of cardiovascular diseases (Soci et al., 2017). Additionally, aerobic physical activity has been shown to reduce levels of TC and LDL-C (Virani et al., 2021).

One of the dynamic and highly engaging sports that can positively affect body composition and lipid profiles is gymnastics. This sport comprises movements that require cardiorespiratory endurance, flexibility, muscle strength, agility, explosive power, muscular endurance, and body coordination (Lemes et al., 2018). Consequently, gymnastics can be an effective means of improving blood lipoprotein levels. Anwar et al. (2023) reported that gymnastics reduces BMI and increases physical fitness in obese children. Additionally, it has been observed that 6 months of mini-trampoline and treadmill training significantly impact weight loss in obese children (Mashaal et al., 2018). In another study, Shakib et al. (2023) reported a significant decrease in miR-128-1 (a microRNA gene associated with various physiological processes), HDL-C, LDL-C, TG, and cholesterol indices following a combined aerobic and strength training regimen in obese subjects. However, the full extent of this training's effectiveness on physiological indicators remains undetermined. Moreover, most exercise programs aimed at reducing weight and improving body composition and lipid profiles in overweight and obese children have primarily focused on aerobic exercises (Pippi et al., 2022). However, incorporating combined exercises like gymnastics could also prove beneficial. Given the significance of childhood obesity and the limited studies on basic gymnastics training in obese children, this study aims to determine whether basic gymnastics training effectively improves body composition and lipid profiles in obese girls.

METHODS

Participants: The study focused on obese female children aged 7 to 11 years in Isfahan, Iran, with a BMI at or above the 95th percentile. These participants were all in a preadolescent stage and enrolled in primary school, where they participated in a standardized physical education (PE) course (one session per week for 60 minutes). Subjects were carefully selected from those who did not engage in regular sports activities outside of their PE courses at school. A total of 30 participants were purposefully chosen and then randomly divided into two groups: a Training Group (TG, n=15) and a Control Group (CG, n=15).

Based on calculations using G* Power software (version 3.1.9.2), the minimum sample size required was determined to be 24 participants (12 in each group), with an alpha level of 5%, a beta level of 80%, and an effect size of 0.30. However, to account for potential dropout during various stages of the research, 15 participants were assigned to each group.

Procedure: This research is a semi-experimental, applied study conducted using a pre-test-post-test design with a control group. The inclusion criteria were specific to obese female children aged 7 to 11 years, with a BMI at or above the 95th percentile. Participants were required to have no prior engagement in weight loss exercises within the past year, not be taking any drugs or supplements, and to be free of tobacco use. Additionally, they should have no history of illnesses or infections affecting immune factors, no acute lower limb injuries within the last six months, and no pain in the trunk or lower limbs.

The exclusion criteria included missing two consecutive practice sessions, failure to cooperate adequately with the intervention, and the occurrence of injuries. One week prior to the start of the training protocol, all participants were thoroughly informed about the program, its benefits, potential risks, and the correct methods for performing basic gymnastics exercises. They were also instructed to refrain from following any diet plans or engaging in physical activities outside the research exercise program during the study.

Additionally, participants were assured that their personal information would remain confidential with the researchers. They were also given the option to withdraw from the study at any stage if they chose not to continue. All participants received the necessary forms to voluntarily and consciously declare their readiness to participate in the study. Following this, the participants were divided into two groups: Basic Gymnastic Exercises and Control. All research procedures were approved by the University's Ethics Committee, with the ethics ID IR.IAU.KHSH.REC.1402.093.

The training protocol was implemented over 12 weeks, with three sessions per week, in addition to the regular PE course. During this period, the Control group maintained their usual daily routines and continued with the PE course. Body composition and lipid profiles were measured in two phases: pre-test and post-test. All applications and tests were conducted at the Takhti Isfahan Gymnastics Hall.

Measurement method: The method of measuring height, weight and body mass index (BMI): To measure height, a German caliper, SECA model 210, with an accuracy of 3 mm was used. The subject stood barefoot with their back against a height measuring tape that was attached to the wall. The subject's body weight was evenly distributed on both legs, with their head, torso, and legs aligned. The back of the legs, hips, and head touched the wall. A ruler was then placed on the subject's head to measure height, which was recorded in centimeters while the subject exhaled.

A digital scale, KEEP FIT model 6657, made in China, was used to measure weight. Subjects stood on the scale wearing light clothing and no shoes, ensuring their weight was evenly distributed on both feet. Body weight was recorded with an accuracy of 0.1 kg. BMI was then calculated using the formula BMI = weight (kg) / [height (m)]^2 based on the height and weight measurements.

Fat% measurement method: Fat percentage (Fat%) was measured using a 10gms/mm^2 Lafayette caliper (Lafayette Inc., USA) by employing the two-point measurement method and applying Slaughter's (1988) equation [(All F: Fat (%) = 1.33 (triceps + subscapular) – 0.013 (triceps + subscapular)^2 – 2.5)] (Rodríguez et al., 2005).

Blood sampling method: To evaluate the biochemical variables, blood samples from the subjects were collected in two phases: pre-test and post-test. In the pre-test phase, one day before the start of the exercise program and after 12 hours of fasting, a blood sample was drawn from the anticubital vein of the left arm while the subject was seated. The sample, with a volume of 10 ml, was collected between 8 and 10 am by a laboratory technician. In the post-test phase, to prevent the acute effects of exercise on the studied variables, blood was drawn 24 hours after the final exercise session, following the same procedure as in the pre-test. The post-test blood sample was also collected after 12 hours of fasting, between 8 and 10 am.

Lipid profile measurement method: Fasting TC, HDL-C, LDL-C and TG were measured by enzymatic colorimetric method using Roche Diagnostics D2400 kit (Basel, Switzerland) (Paoli et al., 2013).

Exercise protocol: The training protocol was implemented over 12 weeks, consisting of 3 sessions per week, each lasting 45 minutes. Each session began with a warm-up of approximately 15 minutes, which included walking, stretching, rolling, and jogging. The main part of the exercise program was divided into three components: displacement, rotation, and balance. These components were organized according to the difficulty of the equipment and the principle of overload (Garcia et al., 2011) (see Table 1). The program concluded with a 10-minute cool-down that involved stretching and light movements. All exercises were performed under the supervision of a trainer to ensure correct execution of the movements.

The intensity of the exercises was monitored using the Karvonen equation to target 50 to 75% of the heart rate reserve: [Target Heart Rate = [(maxHR − restingHR) × %Intensity] + restingHR]. Exercise intensity was measured with a Polar beat meter (CE 0537, N2965, Polar beat T31, made in Finland). Adjustments to the intensity were made as necessary, with eedback provided to the subjects to ensure they remained within the target range.

To analyze the data, descriptive statistics were employed to calculate central tendencies and dispersion indices, with results reported as mean and standard deviation. The Shapiro-Wilk test was used to assess the normality of the data, and Levene's test was utilized to evaluate the equality of variances ($p \geq 0.05$). To test for significant differences in the means between groups (pre-test and post-test), multivariate analysis of covariance (MANCOVA) was conducted using SPSS version 26, with a significance level set at 0.05.

Table1
Basic gymnastics training program

Practical content	Performance	Time/Repetition	week
Warm-up	walking, stretching, rolling, mild running and jogging	15 minutes	1-12
Front balance	right foot, left foot	10-15 second/3R	1-12
Side balance	right foot, left foot	10-15 second/3R	1-12
Arabesque balance	right foot, left foot	10-15 second/3R	1-12
Walking on the line	walking forward, backward and sideways - walking on the toes	10 minutes	1-6
Walking on the balance beam	walking forward, walking on the toes	5 minutes	6-12
Cradle movement	folded leg cradle, one leg cradle, split cradle, straight leg cradle	10 R	1-6
Form of walking	hop,bear walk, jow walk, crab walk, bunny hopping	10-15 minutes	1-6
Jumping	Jump forward, jump sideways, jump backwards	2-3 time/medium distance	6-12
Forward roll	roll tuck, roll feet apart, roll feet split	10 R	6-12
Cool down	stretching, light movements, sit and reach	10 minutes	1-12

R: Repition

RESULTS

The average and standard deviation of the subjects' age, height, weight, BMI and fat % are presented in Table 2. There are no differences in age, height, weight, BMI, Fat%, Cholesterol, TG, LDL-C and HDL-C between the two groups (p > 0.05).

Table 3 indicates that after applying basic gymnastics exercises, body mass index (BMI) and fat percentage decreased significantly in the training group (P=0.001). Table 4 shows that after the implementation of the intervention in the training group, the amount of CT, TC, and LDL-C decreased and the HDL-C values increased significantly (P=0.001).

Table 2
Characteristics of Research Subject

Variable	Training group (n = 15)	Control group (n = 15)	*p*-Value
Age (year)	9.2 ± 0.52	9.6 ± 0.41	0.682
High (cm)	144.42±5.98	145.13±2.4	0.48
Weight (kg)	63.10±3.82	63.290±5.56	0.669
BMI (kg/m²)	30.34±1.92	30.05±2.34	0.712
Fat %	30.48±9.3	31.2±2.37	0.265
Cholesterol (Mg/dl)	172.45±15.31	174.79±3.56	0.348
TG (Mg/dl)	115.16±2.84	108.99±2.74	0.421
LDL-C (Mg/dl)	105.20±1.73	104.2±3.12	0.282
HDL-C (Mg/dl)	44.3±2.17	43.82±9.5	0.164

Values are reported as mean±SD; BMI: body mass index; **Fat%**: fat percentage; **TG**: Triglycerides; **LDL-C**: low-density lipoprotein cholesterol; **HDL-C**: high-density lipoprotein cholesterol.

Table3

Comparison of of BMI and Fat % for training and control groups between pre and post test in obese children.

Variable	Groups	Pre-Test	Post-Test	***P*-value**	F	***P*-value (Beetwen grops)**
(Kg/m^2) BMI	Training group	30.34±1.92	28.76 ±1.12	ʎ0.001	26.96	0.001*
	Control group	30.05±2.34	29.54±2.01	0.39		
Fat%	Training group	30.48±9.3	28.16 ±1.17	ʎ0.001	17.99	0.001*
	Control group	31.2±2.37	30.98±2.37	0.27		

ʎ: significant differences from pre-test to post-test; *****: significant difference between two groups. Values are reported as mean±SD; Significant difference at P≤0.05; **F**: statistical value MANCOVA; **BMI**: body mass index; **Fat%**: fat percentage.

Table 4

Comparison of lipid profiles variables for training and control groups between pre- and post-test in obese children.

Variable	Groups	Pre-Test	Post-Test	***P*-value**	F	***P*-value (Beetwen groups)**
Cholesterol (Mg/dl)	Training group	172.45±15.21	158.25±2.4	ʎ0.001	31.29	0.001*
	Control group	174.79±3.56	172.3±18.6	0.49		
TG (Mg/dl)	Training group	115.16±2.48	106.07±3.1	ʎ0.012	19.39	0.001*
	Control group	108.99±2.74	107.89±19.2	0.61		
LDL-C (Mg/dl)	Training group	105.20±1.73	97.7±3.0	ʎ0.002	32.02	0.001*
	Control group	104.2±3.12	105.01±21.04	0.38		
HDL-C (Mg/dl)	Training group	44.3±2.17	46.9±3.0	ʎ0.001	14.30	0.001*
	Control group	43.82± 9.5	43.01±21.4	0.4		

ʎ: significant differences from pre-test to post-test; *****: significant difference between two groups; Values are reported as mean±SD; Significant difference at P≤0.05; **TG**: Triglycerides; **LDL-C**: low-density lipoprotein cholesterol; **HDL-C**: high-density lipoprotein cholesterol.

DISCUSSION

The present study was conducted with the aim of investigating the effect of 12 weeks of basic gymnastics exercises on body composition and lipid profile in obese children. The results of the study showed that the exercise intervention significantly reduced fat percentage and BMI of obese children (P=0.001). Additionally, a significant decrease in TC, TG and LDL-C, and a significant increase in HDL-C were observed in the basic gymnastics training group (p≤0.002). In line with the results of the present study, Iriyani et al. (2023), in a study investigating the effect of gymnastics on changing the nutritional status and fitness level of overweight and obese adolescents, reported that exercise interventions have an impact on changes in body weight and BMI in this population. Bellicha et al. (2021), in a meta-analysis aimed at summarizing the effects of exercise programs on weight loss, body composition changes, and weight maintenance, showed that exercise leads to significant weight loss, fat reduction, and visceral fat reduction. Similarly, Razavi et al. (2020) observed a significant decrease in BMI in a group focused on physical activity and diet in a study titled "The Effect of Modifying Dietary Habits and Physical Activity (Daily Walk) in the Treatment of Overweight and Obesity in Children." Furthermore, Hajinia et al. (2020), while investigating the effect of a period of interval training (IT) and high-intensity resistance training (HIRT) on lipid profile and body composition in overweight and obese subjects, showed that both weight and body fat percentage decreased significantly in the training groups. These findings were confirmed in a similar study on obese adolescent girls (Hosseini et al., 2014).

To explain these findings, it can be stated that aerobic exercises, such as some basic gymnastics exercises (e.g., walking on the line, walking on the balance beam, cradle movement), increase mitochondrial function, mitochondrial volume, protein turnover, changes in metabolic enzymes of skeletal muscles, the ratio of capillary network to muscle fibers, and insulin sensitivity in obese individuals (Nolan et al., 2009). Additionally, due to the high energy cost and the activation of the AMPK signaling pathway that increases fat oxidation, exercise can reduce body fat percentage (Wedell et al., 2019). Another important mechanism in reducing body fat and BMI following basic gymnastics exercises is the increase in PGC-1α production, which plays a key role in controlling metabolism, increasing fat oxidation, and preventing obesity (Afzalpour et al., 2017). In short, performing basic gymnastics exercises for 12 weeks can, through these mechanisms, impact the utilization of body fat as an energy substrate and ultimately lead to a reduction in body fat, body weight and improve body composition.

Another result of the present study was the reduction of total cholesterol, TG, LDL-C, and the increase in HDL-C levels following the implementation of 12 weeks of basic gymnastics exercises. Previous studies investigating the effect of exercise training on blood lipids have reported conflicting results. Despite this, most published information indicates a close relationship between lipid profile status and physical activity. In agreement with the findings of the present study, Shakib et al. (2023) reported that 12 weeks of simultaneous aerobic and strength training significantly reduced miR-128-1, HDL-C, LDL-C, TG, and cholesterol levels. Similarly, Hajinia et al. (2020) observed weight loss, reductions in body fat percentage, serum TG, and LDL-C levels in overweight and obese subjects following periods of interval training (IT) and high-intensity resistance training (HIRT).

Further supporting these findings, Ramezani et al. (2016) investigated the changes in cardiovascular metabolic risk factors after eight weeks of endurance, resistance, and combination exercises in inactive obese children. Their findings revealed that sports exercises led to decreases in BMI, TC, TG, LDL-C, VLDL, and insulin resistance in the experimental groups. Likewise, Rahmati et al. (2015) examined the changes in serum levels of leptin, insulin, lipid profile, and BMI following a period of speed interval training (SIT) in obese children. The results demonstrated that SIT significantly affected leptin, insulin, and cholesterol levels, improving BMI in these individuals. Souri et al. (2015) also reported that high-intensity training (HIT) exercises likely decrease serum levels of leptin and increase adiponectin in obese children through fat mass reduction.

In this context, Miller et al. (2014) investigated the effect of a short-term, high-intensity circuit training (HICT) program on work capacity, body composition, and blood characteristics in sedentary obese men. Data analysis revealed significant improvements in fat tissue percentage (3.6%), cholesterol (13%), TG (37%), and insulin (18%) levels from before to after the HICT program. Paoli et al. (2013) also showed that high-intensity interval training (HIIT) caused significant decreases in body weight, fat mass, TC, LDL-C, and apolipoprotein B.

Nevertheless, although most studies have reported results consistent with the findings of the present study, there were differences regarding the duration, sample size, population, and exercise interventions used. Various factors, such as differing exercise times, intensities, and durations, can lead to varying results regarding the effect of exercise on lipoprotein levels. However, while the mechanism behind exercise-induced changes in lipoproteins remains unclear, it is likely that exercise increases blood lipid utilization, resulting in decreased lipid levels (Earnest et al., 2013).

The results of numerous studies indicate the beneficial effects of exercise on lipoprotein levels. Physical activity is generally associated with an increase in HDL-C and a decrease in LDL-C and TG. Beyond causing quantitative changes in serum lipids, exercise also positively impacts HDL-C particle growth, composition, and function. It has been reported that regular exercise increases serum HDL-C and apoA-I levels, enhances HDL-C quality and function, and increases total cholesterol content. Furthermore, it boosts antioxidant abilities and reduces TG and oxidized products in LDL-C and HDL-C. As a result, regular exercise with appropriate intensity can endow lipoproteins with more anti-atherogenic properties (Cho et al., 2023).

Aerobic exercise, such as some gymnastic activities, has been proven to affect blood lipid metabolism. By increasing the concentration and activity of lipoprotein lipase (LPL) in skeletal muscles, aerobic exercise boosts HDL-C levels. Moreover, such activities accelerate lipid transport, breakdown, and excretion, reducing fasting or postprandial TG (Shen et al., 2018). In addition to these changes, aerobic physical activity also reduces TC and LDL-C levels (Virani et al., 2021). Similarly, the gymnastics training program in the present study was primarily based on aerobic, strength, and flexibility exercises.

Based on the results of the aforementioned studies, basic gymnastics exercises improve body composition and lipid profile in obese children. Gymnastics is a combination of endurance, flexibility, strength, agility, power and explosive movements. Therefore, this exercise can be an excellent strategy for weight loss and fitness promotion in obese children. It seems that gymnastics exercises promote the oxidation of fats with significant changes in free fatty acids, triglycerides, and lactic acid and can be an important factor in preventing overweight and obesity.

In summary, regular gymnastic training leads to TG consumption by muscle tissue and increases LPL, resulting in more TG hydrolysis. It also improves the efficiency of the PCSK9 enzyme (low-density lipoprotein receptor enzyme), which reduces the absorption of LDL-C and increases its excretion by the liver, and finally, increases the transformation of LXR (liver X receptor) and the expression of ABCA1 (membrane transporter protein) in macrophages and promotes the process of reverse cholesterol transport (RCT) (Wang & Xu, 2017). It is worth mentioning that the subjects studied were obese children who were sitting on the school bench and did not do much physical activity. To create mobility and physical activity for these children, gymnastics is a fun sport that they can follow with interest and enthusiasm and reach an optimal level of physical fitness and fitness.

LIMITATION

This study also had limitations that should be considered when generalizing the results. The research was conducted exclusively on obese female children, so caution is needed when extending the findings to other genders or different populations. Additionally, the sample size was limited to 15 participants per group; a larger sample size and a broader geographical scope would likely enhance the ability to generalize the results to a wider population.

CONCLUSION

The results of the present study showed a significant improvement in body composition and lipid profile after 12 weeks of basic gymnastics training in obese children. Therefore, the implementation of basic gymnastic exercises is recommended to obese children, parents, sports trainers and health centers as a suitable strategy to prevent overweight and obesity.

Disclosure Statement

The authors report no conflict of interest

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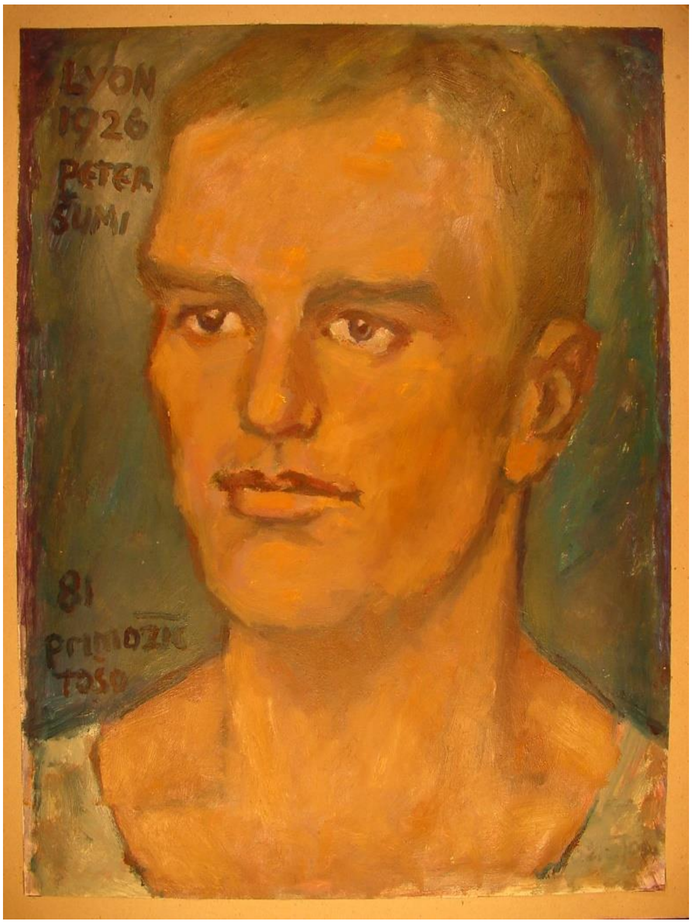
SHORT HISTORICAL NOTES XXXI

Anton Gajdoš, Bratislava, Slovakia
Ivan Čuk, Ljubljana, Slovenia

Ph.D. Anton Gajdoš, born on 1 June1940 in Dubriniči (now Ukraine) has lived most of his life in Bratislava (ex TCH, now SVK). He comes from family of gymnasts (his brother Pavel has world championship medals) and has dedicated his life to gymnastics. His latest achievement is the founding of the Narodna encyklopedia športu Slovenska (www.sportency.sk). One of his passions is collecting photos and signatures of gymnasts. As we tend to forget old champions and important gymnasts, judges and coaches, we have decided to publish a part of his archive under the title Short historical notes. All the information on these pages comes from Anton's archive and has been collected over the years.

PETER ŠUMI (Kranj 29 June 1895 – Wienna 21 May 1981) - the most versatile Slovenian athlete



Portrait of Peter Šumi, made by Jože Primožič (another world champion in gymnastics) in 1981 (Republica Slovenia Archive AS 641)

From the 1st World Gymnastics Championships in 1903 to the 12th World Championships in 1950, not only apparatus disciplines were important, but also track and fild disciplines, swimming, weightlifting and rope climbing. Gymnasts at that time were truly all-around sportsmen's as they competed in athletics and swimming in addition to artistic gymnastics disciplines, and their skills and knowledge can be described as the best sportsmen of all time, as no sport today has such complex requirements. Peter Šumi held the title of the world's best gymnast for eight years with two consecutive victories in the all-around. Although he also excelled on the apparatus, he never competed in the Olympic Games, but he judged gymnastics at the Games in Paris 1924, Amsterdam in 1928 and Berlin in 1936. Considering all his achievements during his competitive period, he is considered the most versatile Slovenian athlete of all time.

Achievements at the World Championships:

1922 SP LJUBLJANA

first place: all-around, rings, horizontal bar, high jump, swimming
second place: team, pommel horse
third place: 100m run, floor exercise

Evaluation of the non-artistic gymnastics disciplines
High jump: 1 m 65 cm, 10 points
(in 1920 at OG Olympic champion Richmond Landon, USA won with 193 cm)
Shot put: 9 m, 10 points
(in 1920 at OG, Olympic champion Ville Porhola, Finland, won with 14,81 m)
Swimming 50 metres: 44 seconds,10 points
(in 1922 the world record for 100 metres was 58,6 seconds by Johnny Weismuller, USA)
Run 100 metres: 12 seconds, 10 points
(in 1920 at OG Olympic champion Charley Paddock, USA won with 10.8 s)

High jump technique at the 1922 World Championships (Archive Faculty of Sport, University of Ljubljana, Slovenia)

1926 SP LYON

first place: all-around, rope climbing,
second place: team
third place: floor exercise, swimming

Evaluation of the non-artistic gymnastics disciplines
Rope climbing 8 m (arms only in L-sit): 8 seconds, 15 points
(in 1924 at OG Olympic champion Karel Šupčik, TCH won with 7,2 s)
Swimming 50 m: 36 seconds, 15 points

1930 SP LUXEMBOURG

second place: pommel horse
third place: pommel horse, team

Peter Šumi held the title of the world's best gymnast for eight years with two consecutive victories in the all-around. Although he was also excellent on apparatus, he never competed in the Olympic Games, but he judged gymnastics at the Games in Paris in 1924, Amsterdam in 1928 and Berlin in 1936. Considering all his achievements during his competitive period, he is considered the most versatile Slovenian athlete of all time.

SLOVENSKI IZVLEČKI / SLOVENE ABSTRACTS.

Anežka Novotná in Iva Burešová

IZKUŠNJA ČEŠKIH VRHUNSKIH AKROBATOV NA VELIKI PROŽNI PONJAVI IN NJIHOVIH VADITELJEV S SINDROMOM IZGUBLJENEGA GIBANJA

V tej raziskavi so preučevali izkušnje čeških vrhunskih akrobatov na veliki prožni ponjavi in njihovih vaditeljev s sindromom izgubljenega gibanja (ang. »Lost move Syndrome« - LMS). Opravljenih je bilo šest poglobljenih polstrukturiranih pogovorov s tremi akrobati (starimi od 13 do 20 let) in njihovimi vaditelji (starimi od 45 do 46 let vaditeljskimi izkušnjami od 20 do 28 let). Izjave smo razčlenili s pomočjo pojmovno razlagalna razčlenitve. Rezultati so prispevali k predstavitvi tega bistvenega, vendar ne dobro opisanega pojava v virih, kar kaže zlasti na pomembno spremenljivost zaznanih vzrokov za LMS. Izražanja LMS na telesu pri posameznih akrobatih so bile precej različne. Strah in nerazumevanje LMS sta bili pogosti duševni težavi vseh akrobatov. Hkrati so bile pomembne razlike med izkušnjo LMS s strani akrobatov in njihovih vaditeljev. Zdi se, da je najpomembnejši dejavnik za razumevanje LMS osebna izkušnja z njim. Rezultati so lahko v pomoč vaditeljem v praksi ali športnim psihologom pri nadaljnjem razumevanju akrobatove izkušnje LMS.

Ključne besede: sindrom izgubljene spretnosti, skoki, pojmovno razlagalna razčlenitev.

Juan Antonio León-Prados in Carmen Ramos

UČINKOVITA METODA ZA OCENJEVANJE IN IZBOLJŠANJE USPEŠNOSTI SODNIKOV MED TEKMOVANJEM: RAZISKAVA PRIMERA V AKROBATIKI

Kdo sodi sodnike v telovadbi? Kako merimo njihovo točnost in skladnost? Kako vemo, ali je sodni postopek pravičen? To odgovornost ima vodstvo tekmovanja. Vendar jim običajno primanjkuje časa za zagotavljanje učinkovitih povratnih podatkov med tekmovanji.
Z uporabo statističnih in matematičnih enačb smo oblikovali in uveljavili samodejno orodje, ki temelji na Excelu, imenovano Samodejno orodje za posamezna poročila sodnikov za akrobatiko, za hitro in enostavno ocenjevanje uspešnosti sodnikov med tekmovanjem, samodejno ustvarjanje in izvoz posameznih poročil, ki prikazujejo natančnost in skladnosti vsakega sodnika na dnevni osnovi, namesto po koncu tekmovanja.
Predstavljamo izkustvene podatke za 76 izkušenih mednarodnih sodnikov, ki ocenjujejo akrobatske sestave na štirih večjih uradnih dogodkih. Skupno 1240 posameznih poročil je bilo razčlenjenih in zaupno poslanih sodnikom med tekmovanjem, 952 pa je bilo razčlenjenih, da bi ocenili, ali so bili ti povratni podatki učinkoviti pri izboljšanju uspešnosti sodnikov med tekmovanjem.
Orodje zagotavlja učinkovite in lahko razumljive povratne podatke, ki temeljijo na dokazih o uspešnosti sodnikov akrobatike med tekmovanjem, hitro in samodejno ustvarja, razčleni in pošilja podatke za vsakega posameznega sodnika, s čimer pomaga pri posebnih nadzornih nalogah tehničnega odbora pri točkovanju med tekmovanji. Predlagamo, da sodniške uspešnosti ostanejo visoke ali se izboljšajo po vsakodnevnem ocenjevanju med večjimi tekmovanji.

Ključne besede: samodejno orodje, sodniki, ocenjevanje, ACROAJIR®

Lucía Selva Antón in María Alejandra Ávalos Ramos

RAZČLENITEV ZAZNAVANJA TELESNE PODOBE PRI »FIT KID« TELOVADCIH

Namen te raziskave je bil razčleniti stopnjo nezadovoljstva s podobo telesa – opredeljeno kot nezadovoljstvo, ki izhaja iz razlike med želeno in zaznano obliko – med telovadci »Fit Kid«. Raziskava je primerjala podatke na podlagi starostnih razponov in ravni tekmovalnosti ter preučila možno povezavo med večjo težo in ITM s povečano skrbjo za podobo telesa. Uporabljen je bil Vprašalnik telesne oblike (ang. »Body Shape Questionnaire« – BSQ), podatki pa so bili razčlenjeni s statističnim paketom SPSS 28.0. Glavne ugotovitve razkrivajo višjo stopnjo nezadovoljstva s telesno podobo na najvišji ravni tekmovanja (državna raven) in pri športnikih z višjim ITM in višjo težo. Natančneje, dejavnik z najvišjimi ocenami je bilo nezadovoljstvo telesa s spodnjim delom telesa. To kaže na večje tveganje za težave s telesno podobo v pozni mladostni dobi in na višjih tekmovalnih ravneh, pa tudi pri tistih z višjimi vrednostmi ITM. Te ugotovitve bi lahko ponudile dragocene vpoglede za vaditelje, ki bi lahko obravnavali ta vprašanja v sodelovanju z strokovnjaki za prehrano in športnimi psihologi.

Ključne besede: nezadovoljstvo s telesom, vitkost, tekmovalnost, ITM, lepotne panoge.

Andrea Marković, Aleksandra Aleksić Veljković, Lucija Milčić, Borko Katanić, Branislav Majkić, Kamenka Živčić

PRILAGODITEV MERSKIH POSTOPKOV IN IZBOLJŠANJE REZULTATOV PRI PREDŠOLSKIH RITMIČARKAH

Namen te raziskave je bil seznaniti predšolske ritmičarke z merskimi postopki in določiti število poskusov seznanitve, potrebnih za izboljšanje rezultatov testiranja. Za raziskavo se je prostovoljno prijavilo 36 ritmičark, starih 5,14±0,79 let (telesna višina: 119,44±5,98 cm; telesna masa: 21,46±3,35 kg). Vse telovadke so bile brez poškodb, redno so vadile (dva dni na teden, približno 60 minut na vadbeno enoto) in so sodelovale na posameznih tekmovanjih B ravni. Glavne ugotovitve so pokazale statistično pomembno razliko med spremenljivkami gibljivosti hrbtenice in nog ($p<0,00$), skoku v daljino z mesta ($p<0,00$), ravnotežju ($p<0,00$) ter upogibu in iztegu ramen ($p<0,00$). Glede na rezultate pridobljene v tej raziskavi lahko seznanjanje pomembno izboljša rezultate merskih postopkov za vse spremenljivke (gibljivost hrbtenice in nog, ravnotežje, skok v daljino z mesta ter upogib in izteg ramen) pri predšolskih rimtičarkah. Te ugotovitve kažejo na več možnosti za nadaljnje raziskave, kot je raziskovanje dolgoročnih učinkov seznanjanja na razvoj gibalnih spretnosti, posebnih mehanizmov, prek katerih seznanjanje izboljša učinkovitost, in njegovega vpliva na različne starostne skupine in ravni spretnosti v ritmiki. Vaditelji ritmike in drugi vaditelji lepotnih športov morajo udeležence usmeriti in seznaniti s postopki meritev, da bi se izognili napakam pri njih.

Ključne besede: gibljivost; ravnotežje; eksplozivna moč; otroci; gibalni razvoj.

Yaiza Taboada-Iglesias, Aldara González-Acuña, Diego Alonso-Fernández, Águeda Gutiérrez-Sánchez

RAZČLENITEV UKRIVLJENOSTI HRBTENICE PRI RITMIČARKAH RAZLIČNIH TEKMOVALNIH RAVNI IN Z RAZLIČNO DRŽO

Za ritmiko so značilne visoke gibalne zahteve hrbtenice, kar lahko privede do sprememb in s tem povezanih poškodb ali bolečin. Namen te raziskave je oceniti in primerjati držo hrbtenice v različnih položajih, gibljivost in zaznavanje bolečine med ritmičarkami. Vzorec je sestavljalo 34 ritmičark (starost: 14,18 ± 2,17) osnovne ravni in ravni zvez. Držo in gibljivost hrbtenice smo razčlenili s sistemom »Spinal Mouse®«, skupaj z zaznavo bolečine (mesto in jakost) in telesno sestavo. Večina telovadk je pokazala normalno ukrivljenost hrbtenice v stoječem in sedečem položaju. Pomembne razlike ($p<0,05$) so bile ugotovljene le v križni krivini med uleknitvijo. Kar zadeva gibljivost v ledvenem delu, so opazili razlike v gibljivosti od stoje do uleknitve, pri čemer so ritmičarke na ravni zvez pokazale večjo nagnjenost k povečani uleknjenosti. Kar zadeva bolečino, je bil najbolj prizadet ledveni predel, saj je 32,4 % primerov poročalo o bolečini. Ugotovljeno je bilo, da so ritmičarke, ki so občutile bolečino, pokazale izrazitejšo ledveno uleknitev v stoji. Med ledveno bolečino in njeno močjo so ugotovili nizko, a pomembno povezavo ($p=0,045$), zmerno povezavo pa med bolečino v kolku in nagibom medenice. Ritmičarke so pokazali večjo nagnjenost k povečani ukrivljenosti v ledvenem delu v stoječem položaju in pri prehodu iz stoje v uleknitev, ki je bila bolj izrazita pri boljših ritmičarkah. Poleg tega se zdi, da obstaja močnejša povezava med povečano uleknitvijo in pojavom ledvene bolečine ter močjo bolečine.

Ključne besede: Spinal Mouse®, antropometrija, hrbtenična ukrivljenost, bolečina, ritmika.

Leroy Donoso Usen in Antoni Planas Anzano

RAZMERJE MED GIBLJIVOSTJO RAMEN IN IZTEGNITVIJO V STOJI NA ROKAH NA RAZLIČNIH ORODJIH PRI TELOVADKAH

Izvedena je bila raziskava s ciljem razčleniti razmerje med gibljivostjo ramen in zmogljivostjo stoje na rokah na treh orodjih ženske orodne telovadbe: na parterju, gredi in dvovišinski bradlji. Sodelovalo je enaindvajset telovadk, ki so bile razdeljene v dve skupini: »G1«, sestavljeno iz dvanajstih deklic, in »G2«, sestavljeno iz devetih mladink, starih 9 oziroma 14 let. Raziskava je bila namenjena preučitvi občutljivih delov za razvoj gibljivosti. S programom Kinovea smo razčlenili ramenski kot (°H) v stoji na rokah in iztegnitvijo vključenih delov sklepov (AJS). Udeleženke so opravile dva različna merska postopka dejavne gibljivosti ramen (GFMT in FIG), rezultate pa so primerjali med skupinama. Pomembne razlike so bile ugotovljene med skupinama pri GFMT ($p = 0,018$), FIG ($p = 0,026$) in AJS v stoji na rokah na gredi ($p = 0,043$). Pomembne povezave so opazili tudi med GFMT in °H na dvovišinski bradlji ($p = 0,021$); in med FIG in °H na gredi ($p = 0,006$), oboje v skupini deklic. Na splošno je imela skupina mladink boljše rezultate, kar je podprlo idejo o boljšem zavedanju telesa in tehničnem obvladovanju stoje na rokah na različnih orodjih ženske orodne telovadbe.

Ključne besede: območje giba, stoja na rokah, ramenski kot, telovadni nastop

Yannick Prosch, Marie-Therese Fleddermann, Lukas Reichert in Karen Zentgraf

ZMOGLJIVOST SKOKA PRI AKROBATIH NA PROŽNIH PONJAVAH IN KAKO GA IZMERITI: RAZVOJ PREIZKUSA PONOVLJIVOSTI SKOKA

Tekmovalna sestava na veliki prožni ponjavi je sestavljena iz desetih točkovanih skokov, pri katerih morajo akrobati na ponjavi pokazati ustrezno moč in vzdržljivost spodnjih okončin. Te zahteve glede vzdržljivosti moči so ocenjene s preskusom ponavljajočih skokov (RJT). Vendar pa obstoječi merski postopki niso zasnovani za ponjave, temveč za moštvene športe. Cilj takšnih preskusov je na primer različno število ponovitev in zmanjšanje časa stika s tlemi, zato primanjkuje posebnih ponovitev in zahtevnosti sestave na ponjavi. Zato je cilj te raziskave razviti RJT posebej za veliko prožno ponjavo, ki bo ocenil višino skoka, zmanjšanje zmogljivosti (PD) med RJT in nihanja od skoka do skoka. Devetindvajset vrhunskih akrobatov na ponjavi (TR) iz mladinske državne vrste (JNS-TR; n = 21) in starejše državne vrste (SNS-TR; n = 8), 21 športnikov iz skakalno zahtevnih moštvenih športov (GS; obsega odbojka n = 15; rokomet n = 6), 16 učencev telesne vzgoje (PE) pa je opravilo RJT, sestavljeno iz dvanajstih ponovljenih skokov. Skupinske razlike so bile razčlenjene z ANOVA in razlike v vrsti na ponjavi s t-testi. Rezultati so pokazali, da je imel TR nižji PD v primerjavi z GS in PE ($p < 0,05$). Telovadci na veliki prožni ponjavi SNS-TR kažejo manjša nihanja od skoka do skoka kot telovadci na prožni ponjavi JNS-TR ($p < 0,05$). TR je pokazal boljše rezultate v RJT glede PD v primerjavi z GS in PE. Na koncu je naš RJT predlagan kot novo orodje za veljavno merjenje uspešnosti ponavljajočih se skokov pri akrobatih na veliki prožni ponjavi.

Ključne besede: razčlenitev uspešnosti, vrhunski športniki, slabša izvedba, telovadna izvedba.

Adis Tabaković, Muhamed Tabaković, Almir Atiković, Semir Mašić in Amila Hodžić

RAZMERJE NAJVEČJE IN SORAZMERNE MOČI SPODNJIH OKONČIN TER UČINKOVITOST IZVEDBE PRESKOKA PRI TELOVADBI

Namen te raziskave je bil preučiti razmerje med največjo in sorazmerno močjo spodnjih okončin ter učinkovitostjo izvajanja telovadnega preskoka. V raziskavi je sodelovalo 30 zdravih, telesno dejavnih študentov (starost: $20,84 \pm 0,99$ let; višina: $179,46 \pm 5,91$ cm; telesna teža: $73,88 \pm 6,43$ kg) Fakultete za šport in telesno vzgojo. Največja moč spodnjih okončin je bila ocenjena z merjenjem največje dvignjene obremenitve (v kg) iz čepa (1RM). Sorazmerna moč spodnjih okončin je bila izračunana tako, da se ocenjeni zadnji čep 1RM deli s telesno maso udeleženca (1RM/BW). Dve vrsti preskoka: skrčka(ST) in premet naprej (FHS) – sta bila uporabljena za oceno učinkovitosti izvedbe skoka. Uporabljene so bile tri kriterijske spremenljivke: (d1) razdalja odskočne deske od preskoka, (d2) razdalja doskoka za preskokom, (d1 - d2) razlika med d1 in d2 ter (pt) splošna ocena uspešnosti preskoka. Rezultati so pokazali statistično pomembne in močne povezave med največjo in sorazmerno močjo spodnjih okončin ter spremenljivkami, ki merijo učinkovitost izvedbe skoka. Najmočnejše povezave so opazili pri (d1), sledijo (d2), (pt) in (d1 - d2). Te ugotovitve lahko služijo kot smernice za razvoj obeh vrst moči spodnjih okončin, kar lahko vodi do izboljšane uspešnosti v preskokih.

Ključne besede: absolutna moč, relativna moč, preskoki, orodna telovadba.

Costas Dallas, Apostolos Theothorpu, Kalenia Papazaogonopoulou in George Dallas

KINEMATIČNE ZNAČILNOSTI ZALETA VRHUNSKIH TELOVADCEV PRI PREMETU NAPREJ NA PRESKOKU

Zalet je temeljni predpogoj za uspešno izvedbo preskoka, saj omogoča telovadcu, da razvije največjo nadzorovano vodoravno hitrost. Namen te raziskave je bil ugotoviti dolžino, pogostost in hitrost korakov med zaletom (približevanjem mizi za preskok) pri izvedbi premeta naprej čez mizo za preskok. Devet vrhunskih orodnih telovadcev, ki so izvajali premet čez mizo za preskok med vadbo, se je prostovoljno udeležilo raziskave. S petimi videokamerami – štirimi nepremičnimi in eno premično – so posneli zalet, naskok in odriv z odrivne deske. Telovadci so izvedli šest poskusov premeta naprej čez mizo za preskok s triminutnim odmorom med vsakim poskusom. Rezultati so pokazali, da je bil zadnji korak krajši od predzadnjega, predzadnji pa daljši od predhodnega. Poleg tega so telovadci pokazali postopno povečevanje zaletne hitrosti, ki je ključni pogoj za uspešen skok, do predzadnjega koraka. Povprečna frekvenca korakov med telovadci je bila od 3,20 do 4,88 korakov na sekundo, medtem ko je bila povprečna hitrost korakov v šestih poskusih med 4,03 in 7,37 m/s. Končno je bilo opaženo postopno povečevanje telovadčeve hitrosti do zadnjega koraka, pri čemer je bil zadnji korak krajši od predzadnjega koraka in predzadnji korak daljši od tistega pred njim.

Ključne besede: Kinematične značilnosti, dolžina koraka, zalet, naskok, miza.

Dimitrios C. Milosis, George Dallas, Evdoxia Kosmidou in Theophanis A. Siatras

RAZMERJA MED LETI VADBE TELOVADCEV, INDEKSOM TELESNE MASE, NADZOROM RAVNOTEŽJA IN TELOVADNO USPEŠNOSTJO

Namen raziskave je bil preučiti povezave med leti vadbe telovadcev, indeksom telesne mase (ITM), nadzorom ravnotežja med izvajanjem stoje na rokah, razovke stojno zanožno in stoji na eni nogi v vzponu ter njihovo uspešnost v tekmovalnih okoljih. V tej raziskavi je sodelovalo 40 mladih telovadcev in telovadk (20 moških; starost: 12,20 ± 1,98 let in 20 žensk; starost: 12,33 ± 2,07 let, povprečje ± SD). Prenosna pritiskovna plošča je bila uporabljena za merjenje najvišjega tlaka, območja nihanja središča tlaka (CoP), premika premočrtne razdalje CoP in hitrosti CoP. Dobljene podatke smo razčlenili z vgrajenim programom (Foot Checker, različica 4.0). Rezultati potrjujejo zanesljivost meritev. Ugotovljene so bile močne pozitivne povezave med uspešnostjo telovadcev na tekmovanju ter njihovimi leti vadbe in ITM, pri čemer so bila ugotovljena tudi razmerja med uspešnostjo in spremenljivkami, povezanimi z nadzorom ravnotežja. Regresijska metoda je pokazala, da imajo leta vadbe, ITM in nadzor ravnotežja pri izvajanju telovadnih prvin napovedni pomen pri določanju njihove uspešnosti na tekmovanju, ob upoštevanju razlik med starostnimi skupinami. Kljub omejitvam raziskave rezultati predstavljajo dragocen prispevek k literaturi z razširitvijo znanja o napovedovanju telovadne uspešnosti na tekmovanju. Poleg tega rezultati zagotavljajo dokaze za prepoznavanje nadarjenosti pri telovadcih, vaditeljem ponujajo vpogled v izboljšanje učinkovitosti vadbe in dajejo priporočila za prihodnje raziskave na tem področju.

Ključne besede: tekmovanje, napovedovanje, telovadci, nadzor ravnotežja, posturografija

Zadriane Gasparetto, Nicole Iasmim Minante da Silva, Higor Alexandre Alves de Oliveira, Paula Felippe Martinez, Cassio Pinho dos Reis, Gustavo Christofoletti, Sarita de Mendonça Bacciotti in Silvio Assis de Oliveira-Junior

ŠPORTNE POŠKODBE PRI MLADIH TELOVADCIH PO IZBRUHU COVID-19: RAZŠIRJENOST IN POVEZANI DEJAVNIKI

Zapore zaradi bolezni COVID-19 so negativno vplivale na prakse vadbe in druge vidike, povezane s telesno pripravljenostjo in vadbo v številnih športnih disciplinah. Ta raziskava je preučevala razmerje med različnimi vadbami in zmogljivostjo ter razširjenostjo mišično-skeletnih poškodb (MI) pri mladih telovadcih po začetku pandemije COVID-19. Vzorec je sestavljalo 67 telovadcev orodne telovadbe (AG) iz Campo Grande, MS, Brazilija, starih od 8 do 17 let. Udeleženci so bili razdeljeni v dve skupini: G1, v kateri so bili telovadci, ki so vadili na daljavo, in G2, v kateri so bili telovadci na vadbi v živo. Preiskovancem so ocenili telesne značilnosti, gibljivost, mišično moč in ravnotežje ter izpolnili vprašalnik za beleženje primerov MI. 23 udeležencev (34,3 %) je prijavilo skupno 34 primerov MI, pri čemer je večina prizadela spodnje okončine. Osem posameznikov je poročalo o vsaj dveh ponovitvenih primerih MI. Poleg tega je G2 pokazal večjo mišično moč, večjo gibljivost in izboljšano ravnotežje. Pogoji vadbe v živo so bili povezani z vsaj desetkratnim povečanjem verjetnosti MI. Tedenski čas vadbe (izpostavljenost) je bil povezan s približno 9-odstotnim povečanjem MI spodnjih okončin, medtem ko so bili dejavniki, kot so starost, dinamično ravnotežje in vadba, neposredno povezani z MI, ki se je pojavil med vadbo na tleh. Skratka, čeprav je bila redna vadba povezana z izboljšano gibalno zmogljivostjo, povezana pa je bilo tudi z večjo razširjenostjo MI, zlasti v spodnjih okončinah. Vaje na parterju so bile glavne okoliščine, v katerih je prišlo do poškodb.

Ključne besede: telovadba; postavitev vadbe; COVID-19; uspešnost; poškodbe

Inês Oliveira Gonçalves, Aldina Sofia Silva, Dimas Pinto, Joana Rodrigues-Carvalho in Joana Costa

EPIDEMIOLOGIJA POŠKODB IN POVEZANI DEJAVNIKI TVEGANJA PRI UDELEŽENCIH SVETOVNEGA PRVENSTVU V TELOVADNIH PLESIH 2022

Vadba je opisana kot preprečevalno in zdravilno sredstvo proti različnim boleznim. Vendar pa je tekmovalna športna vadba povezana s povečanim tveganjem za poškodbe, zlasti pri usmerjeni in zahtevnejših vadbah v mlajših letih. Glede na pomen nadzora in dosedanje raziskave za zaščito zdravja športnikov je bila naša raziskava namenjena opisovanju razširjenosti poškodb med telovadci na svetovnem prvenstvu (SP) v telovadnih plesih (»športni aerobiki«) leta 2022 in razumevanju notranjih in zunanjih dejavnikov tveganja, ki lahko prispevajo k tem poškodbam. Športniki, ki sodelujejo na SP 2022, so bili povabljeni, da izpolnijo vprašalnik o poškodbah, ki zajema zadnjih 12 mesecev njihove vadbe. Za razčlenitev vseh spremenljivk v raziskavi so bili uporabljeni opisni statistični podatki. Triinsedemdeset odstotkov športnikov je poročalo o poškodbah, s povprečno 1,6 ± 1,5 poškodbami, ki so se zgodile enkrat do trikrat v zadnjem letu. Najpogostejše poškodbe so bile poškodbe mišic, zvini sklepov, stresni zlomi in zmečkanine, pri čemer so bili najbolj prizadeti spodnji udi, sledita zgornji del telesa in trup. Kar zadeva dejavnike tveganja za poškodbe, je veliko število športnikov poročalo o duševnem stresu (p=0,043) in zaskrbljenosti glede osebne zaščitne opreme (p=0,042). Glede na to, da se zdi, da sta vrsta poškodbe in prizadeti del telesa povezana z gibi, značilnimi za dejavnost, je treba prenos udarca tal in obutve dodatno preučiti. Poleg tega morajo ukrepi za preprečevanje poškodb vključevati načrte za učinkovito obvladovanje stresa.

Ključne besede: šport; travmatologija; tekmovanje; elita.

Sohila Fakhrian Roghani in Allahyar Arabmomeni

UČINKI 12 TEDENSKIH OSNOVNIH TELOVADNIH VAJ NA TELESNO SESTAVO IN LIPIDNE PRESEKE PRI DEBELIH OTROKIH

Debelost je velik zdravstveni problem v svetu, saj je povezana s številnimi boleznimi. Dokazano je, da osnovne telovadne vaje učinkovito preprečujejo in zdravijo to težavo. S to raziskavo smo preučili učinek 12 tednov osnovnih telovadnih vaj na telesno sestavo in lipidni presek pri debelih dekletih. V tej preizkusni študiji z načrtom meritev pred- in po-vadbi in nadzorno skupino je bilo namenoma izbranih 30 debelih deklet z indeksom telesne mase (ITM) na ali nad 95. percentilom in povprečno starostjo 9,4 leta, ki so bile naključno razdeljene v 2 skupini (skupina pri telovadbi in nadzorna skupina). Postopek vadbe je bil izveden 12 tednov, trikrat na teden in s časom trajanja po 45 minut. Telesno sestavo in indekse lipidnega preseka smo merili dvakrat: pred začetkom vadbe in po zaključku vadbe. Za razčlenitev podatkov so bili uporabljeni multivariatni kovariančni testi.

Rezultati raziskave so pokazali, da je vadba pomembno zmanjšala odstotek maščobe in ITM pri debelih otrocih ($p \leq 0,001$). Poleg tega so opazili pomembno znižanje skupnega holesterola, trigliceridov in lipoproteinov nizke gostote, holesterola (LDL-C) ter znatno povečanje lipoproteinov visoke gostote, holesterola (HDL-C) ($p \leq 0,002$). Te ugotovitve kažejo na ugodne učinke telovadbe na telesno sestavo in lipidni presek pri debelih otrocih. Zato je za izboljšanje teh dejavnikov priporočljiva telovadba.

Ključne besede: telesna sestava, osnovna telovadba, lipidni presek, debelost.

Author: Flavio Bessi

A Resounding Success – International Gymnastics Congress 2024 brings global expertise to Freiburg

Freiburg, Germany – 12 to 13 October 2024 – The XVIII. International Freiburg Gymnastics Congress 2024 took place as usual in mid-October at the University of Freiburg and once again marked a significant milestone in the world of gymnastics education and training. This outstanding event brought together top experts, coaches and researchers from all over the world and created a vibrant platform for the exchange of cutting-edge knowledge and advanced training techniques. The congress provided a unique opportunity for professionals in the field to engage with the latest scientific findings and practical approaches to gymnastics.

A truly international gathering of excellence

This year's congress featured renowned speakers and workshop leaders, including leading academics, national coaches and FIG experts. Highlights included Hiroaki Sato, the current head coach of the Japanese national team, who shared his insights into the training methods that helped Japan win gold at the 2024 Olympic Games in Paris in two inspiring presentations. Other notable contributions came from Marco Bortoleto (BRA), Ivan Čuk (SLO), Monèm Jemni (UK) and Michel Marina (ESP), who offered in-depth presentations on topics such as the physiological demands of gymnastics, innovative strength training, the difficulties of Europe's ever-growing population in relation to the physical characteristics of successful elite gymnasts and the challenges of coach education.

Dynamic workshops and insightful lectures

The two-day event featured a comprehensive program of workshops and lectures tailored to a wide range of participants, from aspiring coaches to seasoned professionals. Below are just few examples of the sessions:

- Athlete-centred training and Olympic preparation: Hiroaki Sato shared his philosophy on fostering intrinsic motivation in athletes and provided valuable strategies for building confidence and achieving peak performance.
- Resilience in Sport: Ivonne K. Herr guided participants through strategies for building emotional resilience and effective leadership, addressing the psychological challenges coaches face in a competitive environment.
- Children in high performance gymnastics – can there be a child-friendly and child-centred approach? Hardy Fink, the long-standing head of the FIG Coach Academy, sensitised his audience to the danger of training increasingly difficult movements with athletes at an ever earlier stage, especially in the pubertal phase.
- Physiological and energetic requirements in gymnastics: Alexander Seemann-Sinn from the Institute for Applied Training Science in Leipzig presented very recent findings on the importance of aerobic endurance in gymnastics, which revolutionise earlier scientific findings.
- The role of gymnastics in healthy ageing: Karmen Šibanc and Maja Pajek explored how gymnastics can support the physical and mental health of older adults and offered practical insights into adapting exercise for longevity and well-being.

The XVIII Freiburg International Gymnastics Congress 2024 was not only an educational event, but also a celebration for the global gymnastics community. Since the first edition in 2006, which began with top coach Mikhail Klimenko, more than 5,600 sports enthusiasts have found their way to southern Germany to take part in this gymnastics event. The unique combination of scientific rigour and practical workshops combined with a friendly and family-like atmosphere ensured that every participant left with new skills, insights, and connections. Attendees had the chance to network with leading figures in the sport, exchange ideas, and gain fresh inspiration to elevate their training practices.

An invitation to the future: don’t miss out the next edition!

The success of this year’s congress sets the stage for even greater events in the future. Whether you are a coach eager to refine your training methods, a researcher passionate about the latest advancements in sports science, or simply a gymnastics enthusiast, the Freiburg International Gymnastics Congress is the place to be.

Don’t miss the opportunity to join us again in Freiburg for an unforgettable experience that will deepen your understanding of gymnastics and connect you with the global gymnastics community. Stay tuned for announcements about the XIX Freiburg International Gymnastics Congress and get ready to be inspired by the very best in the field!

Flavio Bessi

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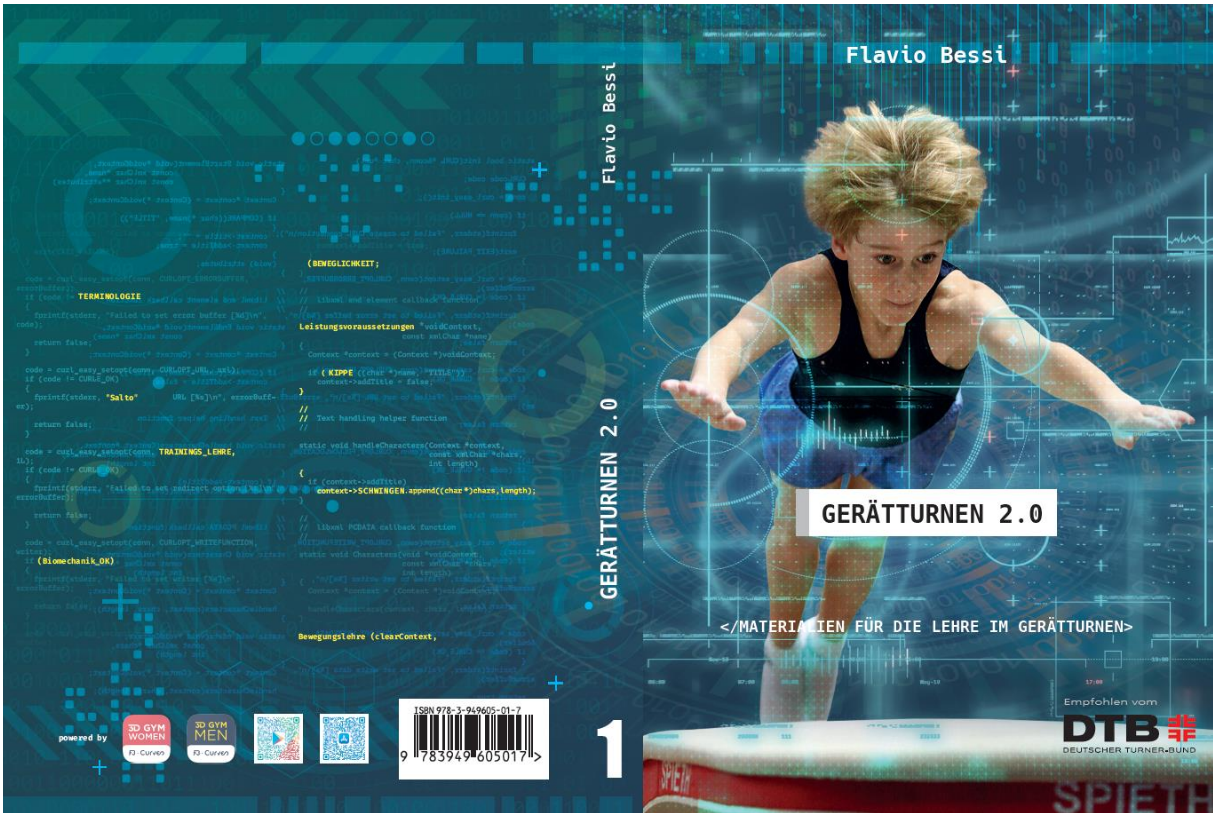
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Die Mitglieder des Autorenkollektivs haben unzählige Bücher, Papers und undokumentiertes Wissen zur Erstellung dieser Sammlung verwendet.
Dieses Werk schafft eine Brücke zwischen den heutigen Erkenntnissen der Wissenschaft und der Anwendung in der Praxis und ist eine sehr komplette, fachliche Zusammenstellung von aktuellstem, wissenschaftlichem Wissen mit direktem Anwendungsbezug im deutschen Sprachraum.
Eigentlich sollte das vorliegende Buch ursprünglich eine Überarbeitung des zweiten Bandes der „Materialien für die Trainerausbildung im Gerätturnen" (Bessi et al., 2010) sein, die im Wesentlichen eine Aktualisierung der Inhalte gemäß der aktuellen Ausbildungsordnung des Deutschen Turner-Bundes sein sollte.
Trotz der unübersehbaren Überschneidungen zwischen Verbandsinhalten und diesem Band ist das Buch jedoch nicht mehr als „das" Material für die Verbandsausbildung zu verstehen.
Die Idee einer reinen Aktualisierung wurde während des Erstellungsprozesses von den Autoren gemeinsam mit der Ausbildungskommission des DTB geändert bzw. ergänzt.
In dem vorliegenden Buch sind zwar alle Themen zusammengestellt, die in den letzten Jahren bei den Trainerausbildungen im Verband unterrichtet wurden, manche Beiträge jedoch gehen sowohl bezüglich des Umfangs als auch der Tiefe weit über das hinaus, was bei einer Trainerausbildung vermittelt und erwartet wird. Zudem muss der Spitzenfachverband flexibel bleiben und daher können auch andere Themen in den Ausbildungen behandelt werden.
Wissenschaftler der unterschiedlichen Disziplinen finden hier wiederum in der Praxis erprobtes Wissen in einer wissenschaftlichen Form aufbereitet, sodass der Dialog und die Annäherung zwischen Theorie und Praxis gefördert wird.
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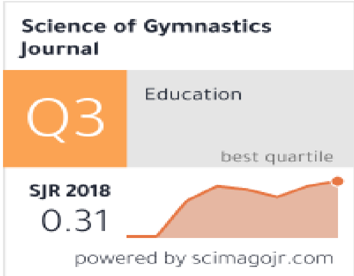

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