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CONTENTS

EDITORIAL

Dear friends,

We are close to the beginning of Olympic Games in Paris. Paris will be hosting games for the third time (1900, 1924, 2024). In year 1900 and 1924 only men competed in artistic gymnastics, in Paris next month we will enjoy men and women artistic gymnastics, rhythmic gymnastics and trampolining. Despite FIG do not govern them, but we will anyway enjoy also in breakdancing and skateboarding (with a lot of gymnastics movements).

Flavio Bessi from University of Freiburg (Germany) in in October preparing symposium on gymnastics. Please be welcome on event, which is bringing new data about gymnastics. Now all the schedules are final.

We are still experiencing problems with our reviewers as, unfortunately, many of them have no time to review our submissions. I would like to appeal to you to please help us out. As a specialized journal, we have access to only a limited number of researchers. Let's all try an effort to remain a part of the prominent scientific community on the Web of Science and SCOPUS!

This issue covers a diverse range of content, the authors are coming from Brazil, Indonesia, Armenia, Poland, Turkiye, Slovenia, Italy, Norway, Spain and Portugal.

Anton Gajdoš with Ivan Čuk prepared 30th short historical note introducing the Paris Olympic Games 1924.

Just to remind you, if you cite the journal, its abbreviation in the Web of Knowledge is
SCI GYMN J.

Please note that our address is

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

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

Ivan Čuk
Editor-in-Chief

MOVEMENT REGULATION IN DISMOUNTS ON THE BALANCE BEAM

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Abstract

In artistic gymnastics, the apparatus structure is considered an essential constraint in regulating gymnastic skill performance under an operating coupling between perception and action. The question arises of how such regulation processes generalize within gymnastic skills with a similar movement goal but a different structure. Therefore, this study aimed to analyze how a particular environmental constraint (space available on the balance beam) regulates gymnasts' performance in skills with a similar movement goal but a different movement structure. Female gymnasts were asked to perform the round-off and the handspring as dismounts on the balance beam in two conditions (baseline vs. reduced space available). Gymnasts exhibited differences in foot positioning between experimental conditions. For both skills, the most significant part of regulation occurred between the starting point and the first step, and a small part of regulation occurred between the first step and the placement of the hands. For the round-off, another small regulation also occurred between the placement of the second hand and landing on the mat; there was virtually no regulation between the placement of the hands and landing on the mat in the handspring. It is concluded that, for gymnasts, adapting to varying constraints from trial to trial can be seen as an essential skill. Implementing these constraints into practice schedules may help develop a broad range of regulation strategies.

Keywords: *perception-action coupling, environmental constraints, handspring, round-off.*

INTRODUCTION

Skills in artistic gymnastics are performed on fixed and stationary apparatuses (Arkaev & Suchilin, 2004; FIG, 2022a; Turoff, 1991). The apparatus structure is considered an essential constraint in regulating gymnastic skill performance (Barreto et al., 2021; Bradshaw, 2004; Davids et al., 2008; Raab, de Oliveira, & Heinen, 2009). Evidence suggests a close and continuous coupling between perception and action when regulating the state of motion in relation to the environment and the movement goal (Cornus et al., 2009; Fajen et al., 2009; Warren, 2006). However, there are various skills in gymnastics, and the question arises of how such regulation processes generalize within gymnastic skills with a similar movement goal but a different movement structure. Therefore, this study aimed to analyze how a particular environmental constraint (the space available on the balance beam) regulates gymnasts' performance in two skills with a similar

movement goal but a different movement structure. The round-off and the handspring performed as dismounts on the balance beam were chosen because both skills share a similar movement goal (i.e., performing a somersaulting motion after hand support to landing upright on the landing mat). Still, both have a different structure (Turoff, 1991): while the round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not.

Theoretical approaches and empirical evidence suggest that skill acquisition involves developing specific contingencies between sensory information and a particular skill's movement requirements (O'Regan & Noë, 2001; O'Regan, 2022). There are various information sources available when performing a particular skill. Yet, the aforementioned contingencies are thought to be developed towards the information that can directly guide actions (Raab et al., 2009; Withagen & Michaels, 2005). Consequently, expert performers can pick up task-relevant information from the environment and use it to regulate their movements to achieve a particular movement goal (Bradshaw & Sparrow, 2001; Bradshaw, 2004; Warren, 2006). For example, when gymnasts move, they may predominantly utilize the visual system to pick up distal information from the environment (i.e., apparatus structure), thereby regulating the current state of motion by exerting forces on the environment when being in contact with a supporting surface (Bardy & Laurent, 1989; Barreto et al., 2020, 2021; Bradshaw & Sparrow, 2001; Haigis, & Schlegel, 2020; Larsen et al., 2016; Lee et al., 1982; Mester, 2000; Latash, 2008; Montagne et al., 2002).

For instance, Bradshaw (2004) analyzed gymnasts' motor behavior during round-off entry vaults. Among other parameters, the onset of visual control was calculated from the run-up kinematics. The author could show that skilled gymnasts use visual information to control the approach run during round-off entry vaults. It could be concluded that using vision in the approach run in gymnastics vaulting enables the gymnast to make corrections from one step to the next to precisely hit the springboard at the end of the approach run. In a similar study, Heinen et al. (2011) had female gymnasts perform handsprings on the vault while manipulating the position of the springboard. The authors could, for instance, show that feet positioning during the approach run and take-off varied predominantly as a function of the position of the springboard, thereby supporting the notion of a visually-driven regulation of the approach run based on the perception of the position of the springboard. Barreto et al. (2021) measured gaze behavior and movement kinematics of gymnasts with different expertise during the approach run and take-off when performing two complex gymnastics skills (double somersault with half twist performed on the mini trampoline either with or without the vaulting table). Results revealed that gaze behavior mainly differed between skills for elite gymnasts, and take-off velocity differed between skills for both groups. It was concluded that differing constraints during skill execution (i.e., the presence or absence of a vaulting table) influenced motor behavior. At the same time, its influence on gaze behavior depended also on gymnasts' expertise.

When performing gymnastics skills, gymnasts experience natural variations in movement execution from trial to trial (Bradshaw et al., 2010; Hiley et al., 2013). This aspect implies the need to gather information from the environment

concerning one's own position, orientation, and state of motion to regulate the ongoing motor skill toward the movement goal within these constraints (Davids et al., 2008; Warren, 2006). In this context, Heinen (2017) studied, for instance, gymnasts' movement regulation when performing cartwheels on a spring floor while manipulating the space available to perform these cartwheels. Results revealed that gymnasts accommodated the manipulated space and that the distribution of regulation in the three cartwheels differed between manipulation conditions. It was speculated that gymnasts regulate motor skills in a stationary environment in a way that accommodates the current configuration of constraints. Heinen et al. (2015) asked female gymnasts to perform two different gymnastics mounts after a short run-up and a reactive leap while apparatus constraints were manipulated (i.e., springboard position). It was found that the hurdle's distance and the feet' placement on the springboard varied between the two gymnastics mounts but not as a function of manipulation of the springboard position. It was concluded that gymnasts show different movement behaviors in tasks with similar movement goals but differing dynamics.

However, there are various skills in gymnastics, and the question arises of how such regulation processes generalize to gymnastic skills with a similar movement goal but a different structure. For example, the balance beam in gymnastics is five meters long, ten centimeters wide, and elevated to a height of 1.25 meters (FIG, 2022b). When gymnasts perform a dismount, they may use a maximum space of 5 meters from one edge to the other edge on the beam to fit in preparatory movement parts such as a run-up or support of the intended dismount. However, the starting point for the dismount usually depends on the previously performed skill, so there is often a natural variation in the execution of dismounts, which demands an adapted regulation from trial to trial (Heinen, 2017; Hiley & Yeadon, 2015). Likely, the relation between the gymnasts' current position and the space available on the balance beam is an essential environmental constraint and might provide relevant information for this regulation (Davids et al., 2005; 2008). Nevertheless, the question arises of how gymnasts regulate dismounts with a similar movement goal but a different structure (Potop & Cretu, 2015; Potop et al., 2022).

For example, a round-off dismount has a similar movement goal as a handspring dismount on the balance beam (i.e., performing a somersaulting motion after hand support to landing in an upright position on the landing mat) but a different structure: when performed from a standing position, gymnasts lunge forward and place their hands toward the end of the beam before performing a somersaulting movement (Turoff, 1991). However, while the round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not (see Method section). Thus, the half-turn in the round-off might enable gymnasts to pick up distal visual information from the landing area during the support phase, which in turn might allow them to regulate the round-off based on current visual information pickup also during the support phase (Davlin et al., 2001; Geiblinger, & Dowden, 2015). This aspect could affect the landing position in the round-off, while this may not be the case in the handspring due to missing visual information pickup from the landing mat during the support phase.

Following the argumentation above, this study aimed to analyze to what extent a

particular environmental constraint (i.e., space available on the balance beam) regulates gymnasts' performance in two skills that have a similar movement goal but are different in movement structure, namely the round-off and the handspring as dismounts on the balance beam. Skilled gymnasts were asked to perform the two dismounts under two conditions (baseline vs. reduced space available). The absolute positions of gymnasts' contact points on the beam and the landing mat were analyzed. It was hypothesized that regulation during the initial phase of the dismounts varied predominantly as a function of the space available on the balance beam (Heinen, 2017). However, regulation during the support and flight phases was expected to differ predominantly between the two skills due to their structural differences during the support phase (Turoff, 1991).

METHODS

$N = 12$ female gymnasts participated in this study. Their age was 11.42 years on average. The gymnasts reported an average practice amount of two to three times a week, and all started gymnastics from a young age, mainly before the age of five. All of them reported doing gymnastics in the german "Leistungsklasse 2" or "Leistungsklasse 4" (DTB, 2023). Every participant reported familiarity with the two experimental tasks (see below). The gymnasts perceived the tasks as easy, so they were considered experts, particularly given their young age (Chi, 2006). The participating gymnasts and their parents were informed about the general procedure of the study, and the parents gave their written consent before the beginning of the study. The study was carried out according to the ethical guidelines of the university's local ethics committee.

Experimental tasks. Gymnasts were asked to perform two different experimental tasks. The first experimental task was a round-off as a dismount on the balance beam. In the second task, the participants had to perform a handspring as a dismount on the balance beam (Turoff, 1991; Figure 1). The balance beam was arranged and adjusted to match the competition guidelines for Women's Artistic Gymnastics (FIG, 2022a). For later analysis, the reference point was defined as the horizontal position of the orthogonal projection of the leading edge of the balance beam. Gymnasts' individual starting points were marked with white tape. From an upright stance, the gymnasts took one step toward the end of the beam, then put their hands on the beam for support, performed the corresponding somersaulting motion, and landed with both feet on the landing mat. Both skills were to be performed in a baseline condition equivalent to each gymnast's starting point. In the second condition (experimental condition), the space available on the balance beam was reduced by 20 centimeters in relation to the individual starting point in the baseline condition. The starting position in the experimental condition was also marked with white tape for orienting purposes.

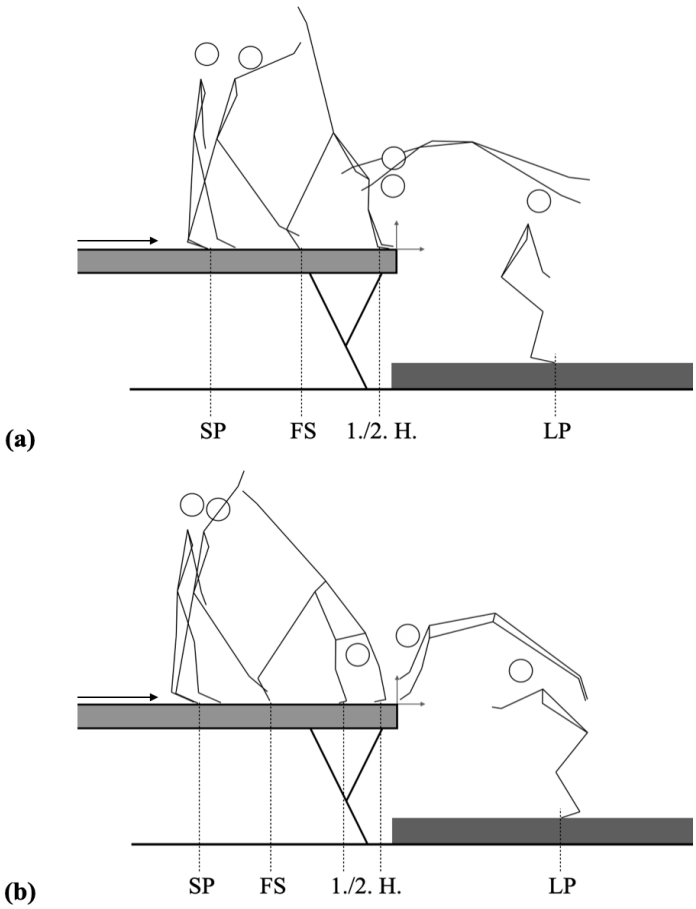

Figure 1. Stick-figure sequences of the handspring (a) and round-off (b) as dismounts on the balance beam (*Note:* SP = starting position, FS = first step, 1./2. H = first and second hand, LP = landing position).

Movement Analysis. Gymnasts' performances were videotaped using a SONY FDR-AX53 video camera. A temporal resolution of 50 Hz was seen as sufficient because only spatial parameters with low regulation velocity were analyzed. A spatial resolution of 1920 x 1080 pixels was also considered sufficient because the space required to perform the experimental tasks was approximately 2.50 meters. The camera was placed approximately 15 meters away from the balance beam. The optical axis was arranged orthogonal to the apparatus axis of the balance beam and aligned towards the leading edge of the balance beam. Camera zoom was adjusted to ensure that the complete performance (starting position to landing) could be recorded with maximized resolution. The camera was calibrated to the gymnasts' movement plane with the help of a 4-meter calibration stick. The horizontal coordinates of the toes of the feet during the starting position, the first step, and the landing on the mat as well as the mid-point of the hands during support on the balance beam (Figure 1), were analyzed using the free video analysis tool Tracker (ver. 6.0.10; https://physlets.org/tracker/). The coordinate origin was set at the intersection between the leading edge and the surface level of the balance beam (0.00 meters in the horizontal and vertical directions). From the performances of each gymnast in each experimental condition, the average values for the aforementioned horizontal coordinates were calculated over all trials and used for further statistics calculations.

Relative differences between contact points and experimental conditions were calculated to estimate movement regulation in both experimental tasks.

The study was conducted in three phases. In the first phase, the gymnasts arrived at the gymnasium with their coaches and parents. The gymnasts, the coach, and the parents were informed about the purpose of the study and the experimental task. After providing consent, the gymnasts had time to warm up for about 20 minutes and to familiarize themselves with the experimental task. In the second phase, the data acquisition took place. The gymnasts' task was to do a round-off and a handspring as dismounts on the balance beam. The order of the tasks was randomized between gymnasts. Both skills were performed three times in both conditions (baseline vs. experimental). All in all, each gymnast completed twelve trials. In the baseline condition, the gymnasts began to dismount from their individual starting positions. In the experimental condition, the space available on the balance beam (i.e., the distance between the individual starting position and the end of the beam) was reduced by 20 centimeters. After data acquisition and in the third phase of the study, the gymnasts were debriefed

The significance level was set at alpha = 5% before data analysis. Separate paired samples *t*-tests were calculated, and Holms correction was applied to control for familywise error rate (Knudson, 2009). The average positions of the toes and the hands (see method section) were used as the dependent variable. We conducted an additional descriptive analysis of relative differences between contact points and between experimental conditions as an indicator of movement regulation.

RESULTS

It was hypothesized that regulation during the initial phase of the dismounts varied predominantly as a function of the space available on the balance beam. However, regulation during the support and flight phases was expected to differ predominantly between skills due to their structural differences during the support phase. According to the *t*-tests, there were significant differences between experimental conditions in the starting point ($t(11) = 10.75$, Cohen's $d = 3.10$), the first step ($t(11) = 5.17$, Cohen's $d = 1.49$), and in the positioning of the first hand ($t(11) = 4.49$, Cohen's $d = 1.30$) for the round-off, and in the starting point ($t(11) = 2.78$, Cohen's $d = 0.80$), the first step ($t(11) = 10.14$, Cohen's $d = 2.93$) the positioning of both hands (first hand: $t(11) = 4.07$, Cohen's $d = 1.17$, second hand: $t(11) = 5.28$, Cohen's $d = 1.53$), and during landing for the handspring ($t(11) = 2.41$, Cohen's $d = 0.70$; all $p < .05$; Figure 2).

Gymnasts performed both the round-off and the handspring in both experimental conditions. While in the round-off, the second hand and the landing on the mat were realized on the same spot in both experimental conditions, there were differences for the handspring in all contact points in both experimental conditions. Considering the relative differences between contact points and between experimental conditions as an indicator of movement regulation, the following results emerged for the round-off: Approximately 45.8% of regulation occurred between the starting point and the first step. In comparison, 29.4% occurred between the first step and the placement of the first hand, and 11.8% occurred between the placement of the first and second hand. The remaining 13.1%

occurred between the placement of the second hand and the landing on the mat. For the handspring, 78.3% of regulation occurred between the starting point and the first step, and 21.3% of regulation occurred between the first step and placement of the first and second hand. In comparison, only 0.4% of regulation occurred between the placement of the second hand and landing on the mat.

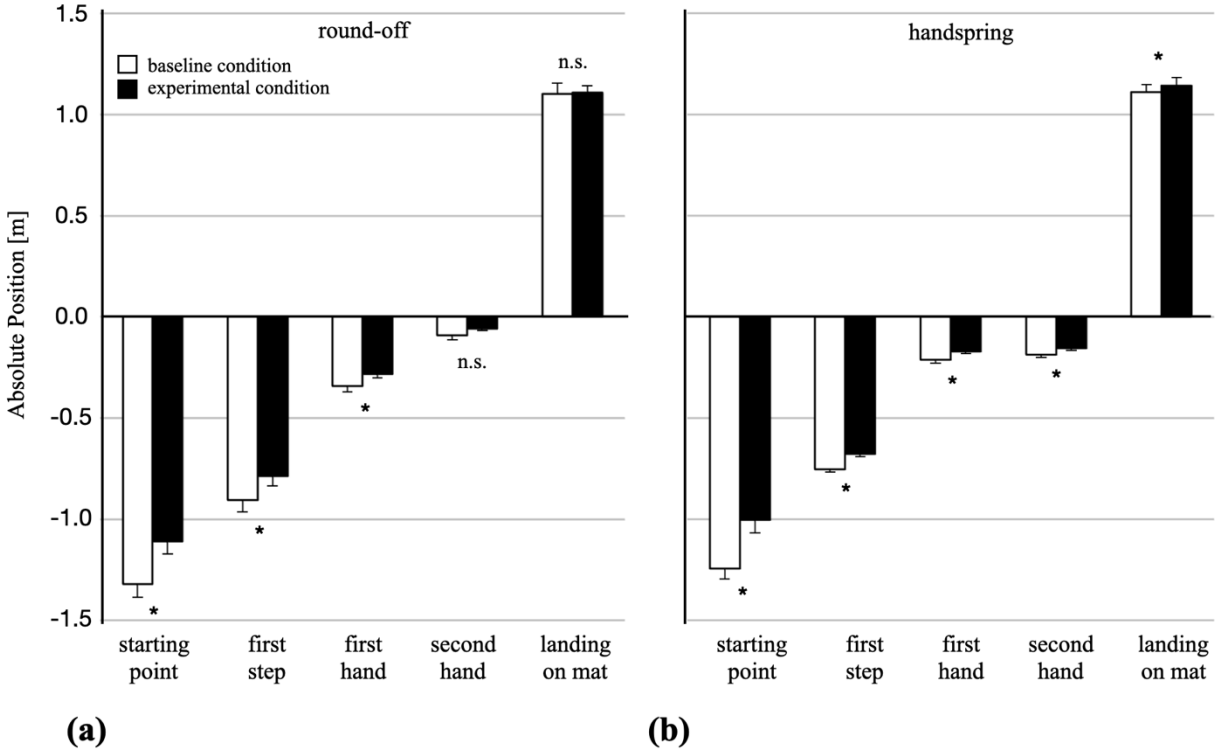

*Figure 2***.** Absolute horizontal positioning during the different contact points when performing the round-off (a) and the handspring (b) as dismount on the balance beam. *Note:* The coordinate origin (0.0 meters) was set at the intersection between the balance beam's leading edge and the surface level. * indicates a significant difference between experimental conditions ($p < 5\%$).

DISCUSSION

This study aimed to analyze to what extent a particular environmental constraint (i.e., space available on the balance beam) regulates gymnasts' performance in two skills that have a similar movement goal but are different in movement structure, namely the round-off and the handspring as dismounts on the balance beam (Turoff, 1991). It was hypothesized that regulation during the initial phase of the dismounts varies predominantly as a function of the space available on the balance beam (Heinen, 2017). However, regulation during the support and flight phases was expected to differ predominantly between skills due to their structural differences during the overhead phase (Turoff, 1991).

The following pattern of results emerged: Gymnasts exhibited differences in foot positioning between experimental conditions in the starting point, the first step, and in the positioning of the first hand for the round-off, and in the starting point, the first step, the positioning of both hands and during landing for the handspring. For both the round-off and the handspring, the most

significant part of regulation occurred between the starting point and the first step, and a small part of regulation occurred between the first step and the placement of the hands. For the round-off, another part of regulation also occurred between the placement of the second hand and landing on the mat; there was virtually no regulation between the placement of the hands and landing on the mat in the handspring.

When being in contact with support surfaces, gymnasts can regulate the current state of motion by exerting forces on the environment based on picked-up information from the environment (Lee et al., 1983; Mester, 2000). While a round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not. The results of our study thus seem to confirm that the half-turn in the round-off might enable gymnasts to pick up distal visual information from the landing area during the support phase, which in turn might allow them to regulate the round-off during the support and toward the landing phase (Davlin et al., 2001; Geiblinger, & Dowden, 2015). This regulation leads to a stable landing position between experimental conditions. However, this is not the case for the handspring due to missing visual information pickup from the landing mat during the support phase.

Gymnasts were asked to perform a handspring and a round-off as dismounts on the balance beam because both skills have the same movement goal but a different movement structure. In competitive gymnastics, these are two relatively simple tasks for advanced gymnasts. The question arises of how movement regulation strategies generalize to gymnastics skills performed under other environmental or task constraints (Barreto et al., 2021; Heinen et al., 2017). Even though we found differences in regulation between the round-off and the handspring as dismount on the balance beam, a particular regulation during the support phase of the round-off might not be necessary given the relatively large landing area. Nevertheless, the landing area is marked with white tape in gymnastics vaulting. One could speculate how this tape might regulate gymnasts' movement performance because landing outside the marked area leads to deductions in judges' scores. Placing the feet and hands on the balance beam results from moving the body's limbs. Yet, in gymnastics, specific angles between limbs are subject to judging, and it might be questionable in further research whether different regulation strategies could potentially impair the technical performance of the skill at hand. Further studies could also assess movement regulation in the same task performed with differing dynamics, assuming that different dynamics could afford a different regulation to achieve the same movement goal (i.e., a round-off performed as a dismount on the balance beam from a standing position versus a round-off performed as a dismount on the balance beam from a short run-up).

Gymnastics involves skills with unique technical requirements (Sands et al., 2003). Thus, for gymnasts, adapting to varying constraints from trial to trial is an essential skill (Schöllhorn et al., 2012). Implementing these varying constraints into practice schedules could be fruitful in developing a broad range of regulation strategies. This idea might enable gymnasts to perform with high stability in different practice and competition situations

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A BALANCING ACT IN SPORTS: HOW COGNITIVE SKILLS CONTRIBUTE TO BETTER GYMNASTIC PERFORMANCE

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Abstract
Professional trainers and athletes often neglect the importance of cognitive skills yet they are arguably among the keys to improving athletes' performance. This study aims to investigate the role of cognitive skills in gymnasts' performance using the correlational method. The research study included thirty-seven young gymnasts (average age of 18.64 ± 0.83 years old) who regularly participated in and were preparing for competitions. Research data were collected from cognitive skills tests and gymnastic performance reviewed by a professional jury. The findings of this study show that better cognitive abilities led to better gymnastic performance, emphasizing the importance of attention, concentration, memory, visuospatial, language, and executive functions. Further research could longitudinally examine the development of athletes' cognitive skills and focus on implementing cognitive training to enhance gymnastic performance.

Keywords: *cognitive skills, gymnastic performance, young gymnasts.*

INTRODUCTION

Optimal performance in sports, specifically at the elite level, requires a balance between physical aspects and cognitive skills. Although we could argue that strength, flexibility, and endurance are highly important (Höög & Andersson, 2021; Marefat et al., 2021; Mkaouer et al., 2018; Russo et al., 2021), the deficiency in cognitive skills could prevent an athlete from reaching their full potential. (Walton et al., 2018). Professional trainers and athletes oftentimes only prioritize physical development without taking into account the fact that cognitive abilities play an important role in improving overall performance (Kilger & Blomberg, 2020). Cognitive abilities such as creativity, mental sharpness, focus, memory, multitasking, and inhibition, have been identified as important factors in predicting athlete's success at the elite level. Especially for athletes who have specialized in sports early on, such as gymnastics, the early development of cognitive abilities can play an important role in helping to deal with the stress and challenges that arise when transitioning to the next stage (Hofer & Clouston, 2014). For instance, in women's artistic gymnastics, athletes must synchronize their movements with music.

Their cognitive capacity to memorize intricate routines and adjust to fluctuations in musical tempo distinguishes between impressive and less satisfactory performances.

Cognitive skills, also known as cognitive abilities or functions, consist of mental processes performed consciously such as thinking, remembering, learning, and using language in communication (Leisman et al., 2016). Cognitive processes are caused by the gradual psychological changes in the brain constructed from interactions with the environment (Cocchi et al., 2017; Grossberg, 2021). Such processes directly affect knowledge acquisition (Cherukunnath & Singh, 2022; Molenaar et al., 2011), and according to Jean Piaget's views on cognitive development, they are also interconnected with maturity, brain development, and environmental adaptation (Barrouillet, 2015; Daskalakis et al., 2013). During one's development, cognitive abilities transform as one gets older and obtains experiences (Hopkins et al., 2016; Park & Bischof, 2013; Riva et al., 2016). The transformation affects one's view in making sense of the world and in responding to the acquired information (Modabbernia et al., 2021). In the early stages of development, children learn through sensory experiences and physical activity, but over time, they begin to use symbols and language to describe their reality. This stage not only includes the ability to think logically and abstractly, but also introduces increasingly complex concepts of problem-solving, creativity and reasoning. This transformation continues into adulthood, where individuals develop the ability to process information, evaluate situations and make complex decisions (Lourenço, 2016).

In recent years, there has been significant attention directed towards the role of cognitive skills and neuroscience in comprehending, predicting, and enhancing the performance of elite athletes (Chuang et al., 2013; García-Monge et al., 2020; Jacobson & Matthaeus, 2014; Negara et al., 2021). This trend is evident from previous studies that have investigated the cognitive performance of athletes (Logan et al., 2023; Stasielowicz, 2020). Other researchers even concluded that basic cognitive abilities could potentially become indicators of athletic achievements in the future (Cona et al., 2015; Montuori et al., 2019; Vestberg et al., 2017). Another study similarly investigated the functions of five primary cognitive abilities: attention and concentration, memory, visuospatial, language, and executive functions (Hendrayana et al., 2020). Those aforementioned studies prove to be highly significant element in understanding how cognitive abilities affect athletes' performance in various sports.

Gymnastics is a branch of sports requiring complex technical skills (Hendrianto & Firmansyah, 2023). It requires coordination of precise movements and the ability to adapt to unexpected situational changes (Diaz-artiles & Karmali, 2021; Hiley et al., 2019; G. K. R. Williams et al., 2016). In gymnastics, several skills are gradually taught in phases (Irwin et al., 2005), in which every phase is aimed at fundamentally preparing one's skills for the next phase, for instance: posture adjustment, balance, flexibility, and muscle strength.

In this context, cognitive skills take center stage. The complex characteristics of gymnastics call for quick decision-making, proper spatial awareness, and quick information processing (Heppe et al., 2016;

Hötting et al., 2021; Von Lassberg et al., 2012). Additionally, attention, concentration, and memory are required to perform certain movements accurately and to coordinate step patterns with the music or choreography (Abdollahipour et al., 2015; Bisagno et al., 2022; de Paula Ferreira et al., 2021; Seidler et al., 2012). Executive functions involving planning, self-regulation, and impulse control (Miyake & Friedman, 2012) are also vital in gymnastics. Gymnasts must be able to plan every movement with precision, manage time efficiently, and control impulses to avoid mistakes. Language ability also enables gymnasts to comprehend creative nuances and movement interpretations and their relevance when interacting with their trainers and teammates (Ivanova, 2022). Those aforementioned cognitive abilities enable athletes to perform under pressure and at high stakes.

Despite the significance of previously explained elements, the precise contribution of cognitive skills in gymnastics is yet to be fully understood. Therefore, this study aims to provide a comprehensive description of the impact of cognitive skills on gymnasts' performance. The study focuses on the question of whether cognitive abilities contribute to gymnasts' performance, since previous studies focused on one cognitive aspect only such as attention, concentration (Nassib et al., 2014), memory (Zisi et al., 2009), or executive functions (Bisagno et al., 2022). Ultimately, this research seeks to investigate the most important cognitive skills in gymnastic performance.

This study anticipates to provide empirical evidence supporting the significance of cognitive abilities in gymnastics, potentially facilitating the development of more effective training programs in the sport. In essence, this study aims to bridge the gap by comprehensively identifying the relationship between cognitive aspects and gymnastics, which has not been fully explored.

One of the important issues in this research is the fact that there is insufficient empirical evidence to support the contribution of cognitive aspects to gymnastic exercise performance. The main objective of this study was to find more empirical evidence that could support the role played by the cognitive components in gymnastic training. It is hoped that this study will not only provide empirical confirmation but also provide a solid foundation for the development of more effective training programs, as the main problem it seeks to address is the lack of a deep and detailed understanding of the causal relationship between cognitive processes and gymnasts' performance enhancement. This study aims to expand our scientific knowledge on how cognitive processes such as concentration, memory, language, executive and visuospatial functions correlate with gymnastics to achieve the best performance.

METHODS

This study employed the correlational method, involving thirty-seven male artistic gymnasts who regularly participated in competitions or undergoing preparations for them. Participants were randomly selected and provided their consent prior to data collection. Data were gathered while participants were in peak physical condition. Detailed physical characteristics are presented in Table 1.

Table 1

Physical characteristics of the research participants

Data	$\bar{x}$ ± Sd	Min	Max	N
Age	19.03 ± 3.88	10	25	37
Height (cm)	155.14 ± 8.07	135	171	
Weight (kg)	50.51 ± 8.56	28	67	
Body Mass Index	20.78 ± 2.18	15	25	

We employed various instruments to collect data, including cognitive tests designed to measure attention and concentration, memory, language, and executive functions.

Attention and concentration were assessed using the Concentration Grid Test (CGT), as described by Weinberg and Gould (2018). The CGT has been validated in multiple studies (Greenlees et al., 2006; Hendrayana et al., 2020; Komarudin et al., 2021; Negara et al., 2021). This test consists of a 10x10 grid marked with two-digit numbers ranging from 00 to 99. To conduct the test, participants require several tools and facilities, including a comfortable indoor room, a concentration test grid drawing sheet, stationery (such as pens or pencils), and a stopwatch. The test procedure involves participants sitting comfortably and relaxed in the designated area, with a minimum distance of 2 meters between each participant. Participants are then asked to complete their provided biodata before commencing the test. Each participant is instructed to connect the numbers in ascending order, from the smallest (00) to the largest (99), using horizontal, vertical, or diagonal lines.

Memory ability was assessed using the Digit Span test, as outlined by Ridsdale (2011) and validated in multiple studies (Alloway et al., 2008; Hendrayana et al., 2020; Woods et al., 2011). The test involved sheets of paper with sequentially arranged rows of numbers, ranging from 3 to 10 digits, for both forward and backward tests. Participants were tasked with repeating back the series of numbers presented by the researcher, either in the same order (forward test) or in reverse order (backward test). The difficulty level increased gradually, with rows of numbers starting from a lower difficulty level and increasing by one digit each time. Participants had two attempts within each difficulty level, with different number sequences, before being considered to have failed that level after making two errors. Each correct repetition earned the participant a check mark (√), while errors were marked with a cross (X).

Language, visuospatial, and executive function skills were evaluated using academic potential tests (Hendrayana et al., 2020). These tests are commonly regarded as measures of an individual's intelligence (Coyle & Greiff, 2021). Academic potential tests typically include verbal or language tests, numerical or mathematical tests, logical reasoning tests, and spatial or visual reasoning tests. As part of cognitive assessment, academic potential tests aim to assess an individual's maximum performance and are utilized to predict their potential achievement.

To evaluate performance in gymnastics, we engage judges who have experience in judging gymnastics or specialized knowledge of the scoring guidelines referring to the Code of Points (Fédération International de Gymnastique, 2022). In gymnastics, there are two judges whose job

is to assess the athlete's performance, namely D Jury *(Difficulty Jury)* and E Jury *(Execution Jury)* (Dallas & Kirialanis, 2010). D Jury is responsible for assessing the level of difficulty, group elements and connections between movements performed by the athlete as well as providing additional marks for successful connections. E jury is responsible for assessing the athlete's overall performance, including technical and artistic aspects. E Jury also grades the quality of the movements performed by the athlete, including body position, speed, and smoothness of movement. After D Jury and E Jury have completed their tasks, the difficulty and performance scores of the athletes are combined to determine the final score of each athlete's performance.

We employed the Statistical Package for the Social Sciences - Version 25.0 (SPSS 25.0) for analyzing statistical data. Descriptive statistical processes included using the average score as the central indicator, standard deviation to assess data distribution, and identifying the minimum and maximum scores to determine the data range. The normality of the data was assessed using the Shapiro-Wilk test, which confirmed that the data were normally distributed. Subsequently, the Linear Regression Test was utilized to examine the correlation between the independent and dependent variables. Statistical significance was set at $p < 0.05$ to determine whether the relationship between the independent and dependent variables was significant.

RESULTS

Table 3

The collected data consisted of cognitive function scores (attention and concentration, memory, visuospatial skills, language, and executive functions) and the gymnasts' performance, as presented in Table 2. Specifically, attention and concentration had an average score of 7.86, with a standard deviation of 2.85, a maximum score of 14, and a minimum score of 3. Memory had an average score of 65.86, with a standard deviation of 5.61, a maximum score of 79, and a minimum score of 55. Visuospatial, language, and executive functions (assessed via academic potential test) had an average score of 440.64, with a standard deviation of 82.55, a maximum score of 588, and a minimum score of 440. Overall, the cognitive skills had an average score of 150, with a standard deviation of 26.51, a maximum score of 212.68, and a minimum score of 110.55.

Table 2 *The descriptive data of cognitive skills and athletes' performance*

Variable	$\bar{x}$ ± Sd	Min	Max
A&C	7.86 ± 2.85	3	14
M	65.86 ± 5.61	55	79
VLEF	440.64 ± 82.55	440	588
CF	150 ± 26.51	212.68	110.55

(A&C) attention & concentration, (M) memory, (VLEF) visuospatial, language & executive function), (CF) cognitive function.

The correlation of cognitive skills with gymnastic scores is presented in Table 3. The correlation significance reached ($r = .727$, $p = .000$) with determination coefficient of ($r^2 = .529$) (see Figure 1). This means that cognitive functions contribute 2.9% to gymnastic performance.

The linear regression test on gymnastic performance

Variable	Correlation r	Correlation r^2	Contribution (%)	*p*
Attention & Concentration	.592	.351	35.1%	.000
Memory	.671	.451	45.1%	.000
Visuospatial, Language, Executive Function	.664	.441	44.1%	.000
Cognitive Function	.727	.529	52.9%	.000

All cognitive aspects, including attention and concentration, memory, visuospatial skills, language, and executive function, were thoroughly evaluated. Results indicate that memory emerged as the primary predictor of gymnastic performance, as illustrated in Figure 2. The correlation significance reached (r = .671, p = .000) with a contribution score of 45.1%. Additionally, attention and concentration had a correlation score of (r = .592, p = .000) and a contribution score of 35.1%. Moreover, the academic potential test had a significant correlation score of (r = .664, p = .000) with a contribution score of 44.1%.

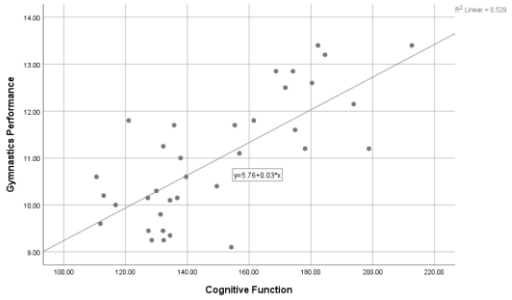

Figure 1. The scatter plot of cognitive functions' contribution to gymnastic performance R= .529; *p* = .000

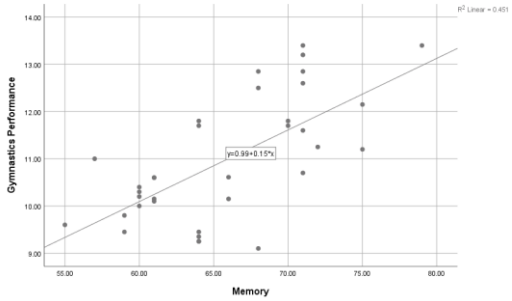

Figure 2. The scatter plot of memory's contribution to gymnastic performance R= .451; *p* = .000

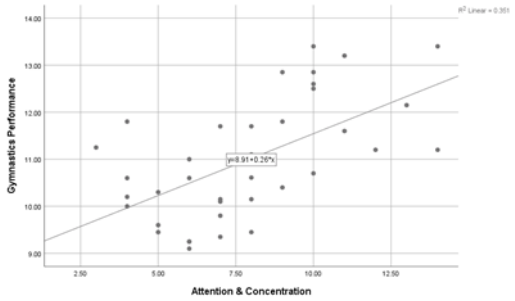

Figure 3. The scatter plot of the contribution of attention and concentration to gymnastic performance R= .351; *p* = .000

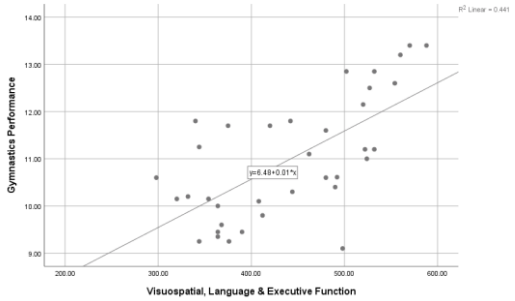

Figure 4. The scatter plot of the contribution of visuospatial, language and executive functions to gymnastic performance R= .441; *p* = .000

DISCUSSION

This study addresses two key objectives. Firstly, we aimed to investigate the role of cognitive skills in the performance of young gymnasts. Additionally, we sought to identify the primary predictor among five cognitive aspects: attention and concentration, memory, visuospatial skills, language, and executive functions. As hypothesized, we initially posited that cognitive skills could serve as predictors of young gymnasts' performance. The results conclusively demonstrate that cognitive skills can indeed

predict the quality of gymnastic performance. These findings build upon previous studies' conclusions, which have highlighted the relationships between attention and concentration and gymnastic performance (Nassib et al., 2014), memory and gymnastic performance (Zisi et al., 2009), and the impact of executive functions on gymnastic performance (Bisagno et al., 2022).

Optimal cognitive skills are undeniably crucial for sports performance, especially at the elite level. There is a complex relationship between cognitive skills and sports activities. While the relationship between cognitive skills and sports activities may not be fully elucidated (Brimmell et al., 2022; Hernández-Mendo et al., 2019; Vaughan & Laborde, 2021), several studies suggest that athletes outperform non-athletes in tasks requiring rapid processing and attention (Isoglu-Alkac et al., 2018), executive functions (De Waelle et al., 2021; Sharma et al., 2019), and spatial memory (Cynthia et al., 2016; Verburgh et al., 2016). It's important to recognize that each sport demands distinct cognitive skills, emphasizing the specificity of cognitive abilities required for performance (Koch & Krenn, 2021; Pačesová, 2021).

In the realm of sports, each type presents athletes with unique cognitive demands. From strategy and tactics to coordination and responses to dynamic situations, the characteristics of each sport vary widely. This perspective aligns with Jean Piaget’s insights into cognitive development, emphasizing the complexity of cognitive growth influenced by neural changes and experiences (Barrouillet, 2015; Choi et al., 2014). Through structured, intentional, focused, and consistent training (Chiappe & Vu, 2019; Eccles et al., 2022; Ericsson, 2020; Moratal et al., 2020), athletes' brain neurons form stronger and more efficient connections (Hosang et al., 2022; Kapilevich et al., 2019; Ludyga et al., 2016; Nakata et al., 2010). This concept aligns with cognitive adaptation, which underscores the brain's ability to adapt to increased physical activity levels. Moreover, environmental experiences, such as engaging in matches, interacting with peers, and learning from professional trainers, are integral to athletes' cognitive development. These experiences enable athletes to develop effective cognitive strategies that enhance their performance.

The results of this study underscore the significant contribution of memory compared to other cognitive aspects. Here, memory refers to the brain's capacity to store, retain, and access information garnered from past experiences (Ofen et al., 2016). The dual process theory (Furley et al., 2015; Imbir, 2016; Shea & Frith, 2016) reinforces the notion that memory plays a pivotal role in predicting the performance of young gymnasts. This theory delineates two primary systems in information processing: automatic and controlled. The automatic system operates unconsciously and efficiently during familiar or routine activities. Conversely, the controlled system involves conscious thought, deep analysis, and planning.

In the context of young gymnasts, memory functions akin to the automatic processing system, enabling athletes to recall and replicate gymnastic movements automatically after rigorous training. However, when executing complex choreographies, the controlled processing system becomes paramount. A robust memory assists athletes in recollecting movement patterns, technical intricacies, and choreographic sequences (Enghauser, 2003; Fukuo et al., 2020), while also aiding

in sustaining mental focus during performances (Furley & Wood, 2016; Unsworth & Robison, 2017).

In this context, concentration refers to athletes' capacity to focus on relevant environmental cues during practice or competition (Oliver et al., 2021). This entails the ability to filter out external and internal distractions that may impede performance. Concentration is sometimes referred to as executive attention in literature (Posner et al., 2019; Rueda et al., 2015; Uus et al., 2020), encompassing mental processes responsible for athletes' stimulus awareness. It activates athletes' perception of stimuli, including visuospatial abilities. During competition, gymnasts must rapidly process visual and kinesthetic information, such as recognizing movements, assessing spatial dimensions, and adjusting body positioning (Barreto et al., 2021). Optimal performance necessitates high concentration, enabling athletes to maintain focus despite external disruptions like audience cheers or internal distractions such as anxiety.

Furthermore, language ability plays a pivotal role in facilitating effective communication between athletes and their gymnastics trainers. Effective communication not only enhances learning but also improves performance in practice and competition (Kim & Park, 2020; A. Williams et al., 2023). Clear communication enables athletes to better receive feedback, leading to accelerated improvements in performance. Communication with trainers, comprehension of instructions and feedback, involve robust executive skills comprising inhibition control, memory, and cognitive flexibility (Diamond & Lee, 2011; Miyake et al., 2000). Athletes must cultivate these skills to regulate impulses, retain pertinent information, and adapt to changing strategies or situations. Additionally, they must actively listen, seek clarification when necessary, and communicate clearly to ensure comprehension of feedback from their trainers. These elements collectively contribute to effective communication between athletes and trainers, fostering optimal gymnastics performance.

In conclusion, all cognitive skills are interconnected and contribute to gymnastic performance. Developing these skills not only enhances gymnasts' cognitive capabilities but also leads to significant improvements in their performance, which necessitates precision in choreography execution.

CONCLUSIONS

Based on the findings and discussions outlined in this study, there is potential for further research to delve deeper into the role of cognitive skills in gymnastic performance. Future studies could longitudinally investigate the development of athletes' cognitive skills by incorporating brain imaging techniques and cognitive training into gymnastic training regimens, particularly among young gymnasts. This approach may enhance their potential, ultimately leading to greater achievements at competitive levels. Additionally, expanding the scope of research to include regional variations (across different countries) and international competitions could provide new valuable insights.

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IMPORTANCE OF BODY SYMMETRY TO ESTABLISH STAND BALANCE AFTER DROP JUMP

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Abstract

The aim of the study was to determine if body symmetry influences the establishment of stand balance after a drop jump. Thirty-two healthy sports students with experience in artistic gymnastics participated in this study. The participants had an average age of 19.8 ± 1.4 years, height of 182.9 ± 6.8 cm and weight of 79.1 ± 8.1 kg. Morphological characteristics were assessed by measuring differences between the left and right sides in forearm girth, upper arm girth, calf girth, thigh girth, long shoulder height, lean mass of legs and lean mass of arms. The standing balance result was calculated based on factor scores obtained from nine measurements taken over 30 seconds after jumping from a 25 cm height platform. These measurements included three for normal stand, three for blind stand, and three for deaf stand. The data was collected using a pressure insoles system and by measuring the difference in ground reaction force between the left and right legs. Stepwise regression analysis revealed that 27% of the differences in leg load could be explained by differences in morphological characteristics between the left and right sides with two significant predictors: the difference in long shoulder height explaining 16% of the variance and the differences in arm lean mass explaining 11% of the variance. Both variables showed a negative relationship with the factor jump standing. It was observed that imbalances in body symmetry could increase the long-term risk of acute or chronic injuries.

Keywords: *3D scan, balance, body symmetry, In Body, jump, pressure insole.*

INTRODUCTION

Artistic gymnastics is classified as a multi-structured sport discipline, as it involves a wide variety of complex motor skills. The possible combinations of these skills further enhance the complexity of motor tasks and expand the range of possibilities (Pegan, 2015).

In all gymnastic disciplines, jumps are a fundamental component. A jump is a motor task consisting of three parts: the take-off, the flight, and the landing (Bolkovič et al., 2002). Landings are crucial in artistic gymnastics as they represent the final element performed after all acrobatic elements. Landings are also executed after

each jump on the trampoline. Similarly, in rhythmic gymnastics, landings follow various jumps.

Marinšek (2007) states that success in elite gymnastics is determined by the landing. Sometimes, the difference between the winner and other competitors is determined by nuances that an inexperienced observer may not even notice. These nuances are crucial for distinguishing the best from the good. An athlete must perform three tasks in a successful landing (Antonov, 1975): a) absorb the impact on the surface, b) maintain a balanced body position upon landing, and c) meet traditional aesthetic requirements. The most challenging task of a landing is maintaining a balanced position upon landing. A balanced landing occurs when the kinetic energy is equal to zero, and the body is at rest (Marinšek, 2007).

In a meta-analysis of studies on the impact of ankle injuries on balance after acute ankle sprain and chronic instability, Wikstrom, Naik, Lodha, and Cauraugh (2010) found that balance impairment is significantly weakened following an acute lateral ankle sprain, which negatively affects balance. Ankle sprains can be assessed as asymmetries in the body, and it can be inferred that postural control is compromised when there are weaknesses on one side of the body.

In a study investigating the differences between the dominant and non-dominant limbs during double-leg landings, it was concluded that the non-dominant ankle exhibits a more effective protective mechanism against excessive joint motion, while the dominant ankle is at greater risk of injury during drop landings (Niu, Wang, He, Fan, and Zhao, 2011).

In another study (Čuk & Marinšek, 2013), researchers explored how temporal, kinematic, and dynamic characteristics of landings relate to landing quality in gymnastics. They found that all predictors defined asymmetries between the legs during landing. Landing and maintaining an upright stable position in sports activities (e.g., artistic gymnastics) or everyday activities (such as landing after jumping on stairs) are important for minimizing the risk of injury.

Pajek, Hedbávný, Kalichová, and Čuk (2016) also analyzed take-offs and landings to determine the actions performed by the left leg, both legs simultaneously, or the right leg of professional female gymnasts in balance beam routines. They concluded that asymmetric lower limb loading is present in the routines of elite gymnasts. However, repeated unilateral stress on a healthy locomotor system may lead to functional abnormalities in human posture.

It's worth noting that the most significant dynamic loads on the lower extremities occur during asymmetrical landings, rather than in unsuccessful landings as typically assumed. Asymmetrical yet reasonably successful landings seem to present the greatest injury potential for the Achilles tendon, knee joint, and spine (Panzer, 1987). The deviation from perfect body symmetry is caused by lack of development accuracy. Systematic sport training creates differences in body posture due to the disparity in the muscular-ligament apparatus on the left and right sides of the torso, which is the result of asymmetric body muscle development (Šarabon et al., 2005).

Čuk et al. (2012) found significant differences in the morphologic characteristics of top-level gymnasts between the left and right arm in elbow diameter, circumference of the forearm, and skinfold thickness of the triceps brachii. However, they did not find any significant

morphological adaptations to asymmetric loads in the legs.

For these reasons, it is reasonable to ask what the relationship is between anthropometric characteristics and landing. Do morphological asymmetries in the body affect the balance position after landing?

Based on the structural complexity of movements in individual sport disciplines, gymnastics is ranked among conventional sports, which are characterized by aesthetic and physically determined cyclical sets of structures to be carried out either in standard or variable external conditions (Matveev, 1977; in Kolar, Samardžija P. & Veličkovič, 2015).

A trainee must constantly adapt to the environment to successfully perform motor tasks (Marinšek, 2007). Three processes characterize every motor task (Schmidt, 1999): a) perception of stimuli (information from the environment), b) response selection (determining what, where, and when to do something), and c) program execution based on response selection.

Information for motor tasks comes from various sources, distinguishing between information coming from the environment and information coming from the body. In sports, vision and hearing provide the most useful environmental information. Among the most important receptors within the body are proprioceptors (Rajtmajer, 1990).

Therefore, in this study, we used different conditions for landing, specifically normal stand, blind stand, and deaf stand.

However, to the best of our knowledge, no studies have been conducted in which dynamic balance abilities after a jump are related to body morphological symmetries. Therefore, the objective of this study was to investigate whether morphological characteristics, especially bilateral asymmetry, influence dynamic human balance. The hypothesis to be tested is (H1) that morphological bilateral asymmetries impact differences in the proportion of ground reaction force (GRF) between the left and right legs in standing balance after jumping from a 25 cm box.

METHODS

Thirty-two sports students registered in the 2015/2016 academic year, who have experience with artistic gymnastics, participated in this study. Their average age was 19.8 ± 1.4 years, their weight was 79.1 ± 8.1 kg, and their height was 182.9 ± 6.8 cm. The subjects' sports orientations were random, and none of them were high-performance athletes. They had no medical conditions. The study was performed in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee. Informed consent for study participation was obtained from all participants.

Our measurements were collected in two stages. In the first part, morphological measurements were taken using a 3D body scanner and the InBody 720 system. The 3D body scanner (NX-16 [TC]2, Cary, North Carolina) scans the whole body and produces a true-to-scale 3D body model. A multi-scan option with 3 consecutive scans was used to obtain the data. Each set of 3 consecutive scans lasted for 24 seconds, and subjects were instructed to remain as still as possible. Previous research (Zancanaro, 2015) has shown the reliability of anthropometry performed by different skilled anthropometrists using a 3D scanner (ICC = 0.996-1.0 for repeated digital measurement). The InBody 720 bioimpedance device measures each individual with high repeatability (Biospace, 2008), and its measurement methods are

reliable and valid. The validity of the device InBody 720 device was confirmed by So *et al*. (2012) in a study that showed significant correlations between body composition measurements taken using the body composition measurements taken with air displacement plethysmography and eight-polar bioelectrical impedance analysis, specifically for fat-free mass (M: r=0.911) and body-fat mass (M: r=0.938).

From 3D body scanner (according to ISO 20685:2010 norms) the following measurements were taken: forearm girths (the largest circumference between the wrist and the elbow), upper arm girth (biceps measured 5.08 cm below the armpit), calf girth (largest circumference between the knee and the smallest part of the leg above the ankle), thigh girth (largest circumference between crotch level (-2.54 cm) down to the knee), and long shoulder height (vertical line from the shoulder point to the floor, indicating the height of the shoulder point above the floor). Measurements of lean mass in the legs and arms were obtained from the InBody 720.

The second part of the measurements involved body balance maintenance tests. All participants used two in-shoes insoles with pressure sensors (PedarX, Novel GmbH, Munich, Germany), adjusted to their feet size. To prevent shoes from affecting ankle balance, participants did not wear shoes but had insoles placed between two pairs of socks. The PedarX system was secured with an elastic belt around the subject's waist in the middle of the back, allowing for unrestricted movement without imposing asymmetric loads on their feet. The total weight of the PedarX system is 0.400 kg. Data were wirelessly transferred from the system to the computer using a built-in Bluetooth module. The PedarX measurement system has been proven to be accurate, reliable, and valid (Boyd et al., 1997).

Participants performed three types of measurements, each with three repetitions. Each repetition lasted for 30 seconds, starting with the first contact of the feet with the floor after flight. The first measurement was a still-standing position after jumping from a 25 cm high box (Figure 1). Measurements of post-landing balance establishment are valid and reliable for assessing balance during the transition from dynamic to static states (Colby, Hintermeister, Torry, Steadman, 1999; Goldie, Bach, Evans, 1989; Kinzey and Armstrong, 1998 as cited in Wikstrom, 2003) and have been utilized in various studies (Viber and Wojtys, 2001; Onate, Cortes, Welch, and Van Lunen, 2010; Mohammadi, Salavati, Akhbari, Mazaheri, Khorrami, and Negahban, 2012).

All subjects stood with their feet together, hands close to their bodies, and facing forward. The second measurement was a blind still-standing position after jumping from a 25 cm high box, where participants wore glasses with dimmed lenses that prevented them from seeing through them (Figure 2). The third measurement was a deaf still-standing position after jumping from a 25 cm high box, where participants wore protective earmuffs (3M™ PELTOR™ Optime™ II) with an attenuation rating of 31 decibels (Figure 2). All measurements were conducted randomly, and participants had 15 seconds of rest between each measurement.

Figure 1. Subject before jump from a 25 cm high box.

Figure 2. Dimmed glasses and ear muff.

The PedarX system collected results separately for the left and right foot regarding ground reaction force (GRF). The scanning rate was 50 Hz, with a time per frame of 0.02 seconds. GRF results for the left and right foot were recorded every 0.02 seconds. The absolute difference in force load between the legs was calculated every 0.02 seconds, as well as the average difference throughout the entire measurement. The calculation was performed by subtracting the GRF on the right leg from the GRF on the left leg. Perfect balance was indicated when the forces on both legs were equal. The variables included the difference between left GRF and right GRF while still-standing position after jumping (Diff. Jump Standing), the difference between left GRF and right GRF while in a blind still-standing position after jumping (Diff. Jump Blind Standing), and the difference between left GRF and right GRF while in a deaf still-standing position after jumping (Diff. Jump Deaf Standing).

For the analysis, we used the absolute difference between specific morphological characteristics on the left and right sides. The anthropometric variables included the difference between left and right calf girth (Diff. Calf Girth), the difference between left and right upper arm girth (Diff. Upper Arm Girth), the difference between left and right forearm girth (Diff. Forearm Girth), the difference between left and right thigh girth (Diff. Thigh Girth), the difference between left and right long shoulder height (Diff. Long Shoulder Height), the difference between left and right arm lean mass (Diff. Arm Lean Mass), and the difference between left and right leg lean mass (Diff. Leg Lean Mass).

All data were analyzed using Microsoft Excel 2010 and the statistical package SPSS 22.0. First, a Kolmogorov-Smirnov test was

conducted to assess the normal distribution of variables. Pairwise t-tests were then performed to compare the results between the left and right sides. Additionally, reliability tests, such as factor analysis and Cronbach's alpha, were conducted.

The evaluation of balance was conducted in two steps. In the first step, factor analysis (principal components) was performed for each type of standing position. From three items of each type of landing, we calculated Factor Diff. Jump Stand, Factor Diff. Jump Blind, and Factor Diff. Jump Deaf, and factor scores were calculated for the first factor using a regression model. In the second step, the factor scores Factor Diff. Jump Stand, Factor Diff. Jump Deaf, and Factor Diff. Jump Blind extracted jointly the first factor, which we named Factor Jump Standing, and calculated factor scores by a regression model. Factor scores from Factor Jump Standing served as the dependent variable in the regression analysis.

Regression analysis (Stepwise method) was performed to assess the relationship between the dependent variable, the difference in GRF between the legs (left/right leg), and the independent variables representing the differences in morphological characteristics (left/right side of the body). All statistical analyses were tested at $p < 0.05$.

RESULTS

All variables followed a normal distribution, except for the difference between left and right calf girth and the difference between left and right forearm girth, as indicated by the Kolmogorov-Smirnov test. Despite this deviation from normality, multivariable analysis was still conducted, as the dependent variable was normally distributed. The overall reliability (Cronbach's alpha) for the difference in GRF between the legs during jump still-standing, jump blind still-standing, and jump deaf still-standing was 0.888. This reliability level aligns with the findings of Lindmark et al. (2012) and Newton (2001) (cited in Sibley et al., 2015).

In Figure 3. there is an example of the subject's left and right GRF and the difference between them is depicted. In this example, the difference in GRF between left and right leg is 41.82 N ± 64.24. This value varies among tested subjects and is individually determined. The figure illustrates distinct differences in leg use among participants.

The results of the regression analysis, examining the relationship between the dependent variable (Factor Jump Standing) and the independent anthropometric variables, were found to be significant at $p < 0.05$

Table 1
Descriptive statistic.

	Mean	Std. Deviation	K - S	Maximum	Minimum
Diff. Calf Girth [cm]	0.05	0.51	not	0.90	-1.60
Diff. Upper arm Girth [cm]	-0.33	1.12	n	2.10	-2.70
Diff. Forearm Girth [cm]	-0.48	0.81	not	2.50	-1.60
Diff. Thigh Girth [cm]	0.34	2.34	n	5.60	-4.90
Diff. Long Shoulder Height [cm]	-1.17	1.74	n	3.50	-3.70
Diff. Arms Lean Mass [kg]	-0.04	0.12	n	0.17	-0.39
Diff. Legs Lean Mass [kg]	-0.04	0.13	n	0.39	-0.22
Diff. Jump Standing1 [N]	12.49	71.77	n	126.58	-157.83
Diff. Jump Standing2 [N]	15.91	64.29	n	147.28	-109.02
Diff. Jump Standing3 [N]	19.36	60.91	n	151.08	-96.59
Diff. Jump Deaf Standing1 [N]	3.08	74.70	n	108.54	-241.92
Diff. Jump Deaf Standing2 [N]	12.11	68.84	n	154.74	-138.70
Diff. Jump Deaf Standing3 [N]	7.24	55.85	n	129.91	-127.75
Diff. Jump Blind Standing1 [N]	33.11	85.15	n	164.68	-139.82
Diff. Jump Blind Standing2 [N]	13.24	75.91	n	173.76	-184.64
Diff. Jump Blind Standing3 [N]	5.71	60.97	n	147.57	-145.82
Factor Jump Standing	0.00	1.00	n	1.86	-2.89

Legend: n – normal distribution, not – not normal distribution

Figure 3. Example of ground reaction force for right and left leg while still standing after jump from 25 cm high box.

Table 2
Results of Factor analyses.

	Commun-alities	Total Variance Explained Initial Eigenvalues		Compo-nent matrix	Cronbach's alpha
	Extraction	Total	Cumulative %		
1. Diff. Jump Standing1	0.56	1.85	61.45	0.75	0.681
2. Diff. Jump Standing2	0.89	0.66	83.42	0.83	
3. Diff. Jump Standing3	0.60	0.50	100.00	0.78	
1. Diff. Jump Deaf Stand. 1	0.67	1.91	63.65	0.82	0.711
2. Diff. Jump Deaf Stand. 2	0.80	0.76	89.01	0.89	
3. Diff. Jump Deaf Stand. 3	0.44	0.33	100.00	0.67	
1. Diff. Jump Blind Stand. 1	0.72	2.20	73.23	0.85	0.810
2. Diff. Jump Blind Stand. 2	0.82	0.52	90.63	0.91	
3. Diff. Jump Blind Stand. 3	0.66	0.28	100.00	0.81	
1. Factor Diff. Jump Stand.	0.76	2.40	79.82	0.87	0.873
2. Factor Diff. Jump Deaf Stand.	0.86	0.38	92.51	0.93	
3. Factor Diff. Jump Blind Stand.	0.78	0.23	100.00	0.88	

Table 3
Pearson's correlation coefficients between variables.

	Diff. Calf Girth	Diff. Upper arm Girth	Diff. Forearm Girth	Diff. Thigh Girth	Diff. Long Shoulder Height	Diff. Arms Lean Mass	Diff. Legs Lean Mass
Diff. Calf Girth	1						
Diff. Upper arm Girth	0.02	1					
Diff. Forearm Girth	0.25	0.32	1				
Diff. Thigh Girth	-0.24	-0.01	-0.29	1			
Diff. Long Shoulder Height	0.07	-0.34	0.07	0.23	1		
Diff. Arms Lean Mass	0.05	0.21	0.38*	-0.18	0.09	1	
Diff. Legs Lean Mass	0.36*	0.05	-0.05	0.04	-0.03	0.00	1
Factor Jump Standing	-0.23	0.16	-0.27	-0.06	-0.41*	-0.37*	-0.18

*Notes: Pearson correlation coefficient, $p < 0.05$, * significant*

Table 4
Results of Stepwise regression analysis; dependent variable Factor Jump Standing.

Step	R (Uncorr.)	R Square	F Change	df1	df2	Sig. F Change
1	0.41	0.16	5.9	1	30	0.022*
2	0.52	0.27	5.4	2	29	0.010*

	Unstd. Coefficients		Std. Coefficients	t	Sig
	B	Std. Error	Beta		
Constant	-0.36	0.19	-0.41	-1,88	0.069
diff Long Shoulder High	-0.22	0.09	-0.38	-2.36	0.025*
diff Arms Lean Mass	-2.88	1.38	-0.33	-2.09	0.046*

*Notes: $p < 0.05$, * significant*

DISCUSSION

The primary finding of this research is that morphological bilateral asymmetries have an impact on differences in leg GRF during stand balance after a jump from a 25 cm high box. Significant differences were identified in forearm girth and long shoulder height, indicating an asymmetric body posture among the participants. Specifically, the left arm height and forearm girth were lower compared to the right side, which may be attributed to differences in fat mass rather than lean mass.

Although these asymmetries in body posture may seem small and potentially insignificant in normal life, they play a crucial role in determining leg load. For instance, the lower left shoulder height indicates a higher load on the right leg (Table 3). These findings expand upon the observations of Šarabon et al. (2005), who previously identified significant bilateral asymmetries only among individuals involved in unilateral sports. This study demonstrates that even recreational-level sports activities can lead to bilateral asymmetries in body posture.

Reliability analysis (Table 2) via factor analysis showed that cumulative explained variance with the first factor is from 61.5% for normal standing, through 63.7% for deaf standing, to 73.2% for blind standing can be defined as reliable tests. Cronbach's alpha had even higher values (respectively 0.681 for normal stand after jump, 0.711 for deaf stand after jump and 0.810 for blind stand after jump). Furthermore, factor analysis of factor scores for each type of stand balance after jump measurements extracted the first factor with 79.8% of variance and Cronbach's alpha of 0.873. This analysis revealed that the somatosensory system, as described by Shumway-Cook and Horak (1986), played a significant role in postural balance.

The regression analysis demonstrated that 27% of the differences in GRF during stand after a jump could be explained by morphological characteristics (Table 4). The significant predictors were the difference in long shoulder height (16%) and the difference in arm lean mass (11%), both exhibiting a negative relationship with leg GRF differences.

Comparing these findings to previous research, Alonso et al. (2015) found that anthropometric variables explained more variance in medial-lateral postural variability (12% eyes open, 18% eyes closed) compared to the anteroposterior direction (6% eyes open, 0% eyes closed). Although the current study did not specifically discuss the reasons for this difference, it observed a higher overall percentage of explained variance.

Greve et al. (2007) researched the correlation between body mass index and general postural balance, including the anteroposterior stability index and lateral stability index on dominant and non-dominant legs. They found no statistically significant differences in balance indexes between the dominant and non-dominant legs, which is consistent with the current study where only one pairwise t-test out of nine showed a significant difference in leg load between the left and right legs (specifically, during the first attempt of a blind jump).

CONCLUSIONS

The study examined the impact of morphological bilateral asymmetries on leg GRF differences in stand balance after a drop jump from a 25 cm height. It can be concluded that morphological bilateral

asymmetries exert a notable effect on leg GRF differences during stand balance after a jump. The study highlights the significance of maintaining symmetrical body loads to uphold balanced body posture and minimize the risk of acute or chronic injuries associated with imbalances.

To summarize the main conclusions:

- Bilateral differences in morphological characteristics were observed among active sports students, with significant variations noted in forearm girth and long shoulder height.
- Morphological bilateral differences significantly contribute to variations in leg GRF during stand balance after a jump, explaining 27% of the variance.
- The best predictors of leg GRF differences were the disparities in long shoulder height (explaining 16% of the variance) and arm lean mass (explaining 11% of the variance).
- Both predictors exhibited a negative relationship with leg GRF differences, suggesting higher values on the left leg GRF side, higher values of right long shoulder height, and higher values of right arm lean mass.

Maintaining symmetrical body loads is critical for preserving symmetrical body posture and reducing the risk of injuries associated with imbalance.

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THE RELATIONSHIP BETWEEN STRENGTH CAPACITY AND MOTOR PERFORMANCE IN THE GYMNASTIC HANDSTAND: A MACHINE LEARNING STUDY

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Abstract

The present study investigated the relationship between strength capacity and motor performance in the gymnastic handstand. The hypothesis stipulated a positive relationship between motor performance and strength capacity levels. Thirty-two university students, 16 female and 16 male (24.03 ± 4.74 years of age,) participated in the study. The handstand was assessed using the absolute error of the three angles produced by the model (video) and the three angles produced by the performer. We conducted four strength tests: explosive force, maximum right-hand grip strength, maximum left-hand grip strength, and resistance force. The machine learning model was trained using 10 of the folds and cross-validated, and a linear regression test was performed using motor performance (absolute error) and strength tests (explosive force, maximum force right-hand, maximum force left-hand, and resistance force). The results showed that the machine learning model indicated a low relationship between strength capacity and motor performance. Additionally, motor performance was not found to be related to strength capacity. The results may indicate that specific capacities and the interaction of factors such as task specificity, environment, and individual characteristics influence motor performance.

Keywords: *sport, training, motor task, motor control, motor behavior.*

INTRODUCTION

The field of sports preparation is complex, involving the selection and assessment of athletes (Malina, 1974). In the development of these programs (Baker et al., 2012; Vaeyens et al., 2008; Mohamed et al., 2009), athletes are typically evaluated across a range of skills specific to their sport, as well as through general tests aimed at assessing capacities such as flexibility, endurance, and strength (Vaeyens et al., 2008; Mohamed et al., 2009). However, the relationship between these specific skills and capacities, particularly in the context of

gymnastics handstands, remains an ongoing investigation.

Initial studies have adopted the perspective that capacities can predict sports success. They were grounded in a fundamental (general) capacity capable of elucidating performance across numerous skills, thus fostering success in sports (Brace, 1930; McCloy, 1934). It implies that capacity comprises attributes intricately linked to executing various movements (Rarick, 1937; Carpenter, 1942).

Although some studies have supported the perspective of a general capacity (Ibrahim et al., 2011; Liefeith et al., 2018; Hands, McIntyre, and Parker, 2018), other researchers have not revealed favorable results and have followed the perspective that performance may depend on the specificity of the task (Lage et al., 2017; Robin et al., 2005; Tremblay & Proteau, 1998), i.e., motor tasks can be influenced from a discrete set of capacities in a specific manner. Following this perspective, studies indicated that capacities such as coordination and agility, considered by some researchers as 'general capacities' transferable to a series of sports skills, are specific to certain motor tasks (Henry, 1968). The general capacity perspective has raised numerous questions and should have stimulated more research that supports this view (Ibrahim et al., 2011; Hands, McIntyre, and Parker, 2018).

Another perspective highlights the complex interaction among task demands, environment, and individuals in shaping motor performance (Newell, 1985;1986). In gymnastics, examples of task demand constraints include the routine's complexity and the timing and sequence of movement execution. Environmental constraints, for example, in gymnastics, encompass the temperature and humidity of the gymnasium. Individual constraints refer to inherent characteristics and attributes specific to the athlete, which can influence motor performance. In gymnastics, individual constraints may manifest through capacities such as flexibility, coordination, and strength. Therefore, the most crucial aspect is not an isolated element (such as individual characteristics like capabilities) but rather the interaction among these elements.

Currently, there is a lack of information about the studies that sought to relate specific skills to these propositions (Hands, McIntyre, and Parker 2018). In the context of gymnastics, tests evaluating athletes' capabilities serve as a method for athlete selection (Mkaouer et al., 2018). Among these capabilities, strength capacity stands out as a crucial component (Halin et al., 2002). For instance, Nassib et al. (2020) discovered that elite-level gymnasts demonstrate superior muscular strength in various forms, such as isometric, explosive, and resistance, surpassing the benchmarks established by the International Gymnastics Federation. Given the significance of capabilities in gymnastics, understanding their relationship with performance in specific tasks becomes paramount.

Therefore, the primary objective of this study was to delve into the relationship between strength capacity and motor performance in the context of gymnastics handstands. By employing machine learning models and linear regression, we aimed to uncover the intricate connection between strength, in its various forms, and motor performance. The anticipated outcome is a positive correlation between motor performance and strength capacity levels, a finding that could significantly impact the field of sports science and gymnastics.

METHODS

Thirty-two university students, 16 of whom were female, and 16 were male (24.03 ± 4.74 years of age) participated in the study. As criteria for participation in the experiment, the individuals had to be able to raise their legs. At the same time, both hands had to touch the ground, forming an angle of at least 90° between the Patella and Iliac crest (Rohleder & Vogt, 2018). Volunteers could not have a systematic experience with handstand skills and did not present any pathology that could directly interfere with movement performance. The selected volunteers were informed of the purpose of the study and provided their written informed consent to participate in this study. The experiment was reviewed and approved by the local Ethics Committee (BLIND INFORMATION) and was conducted in agreement with the 1964 Declaration of Helsinki.

We selected these tests to assess strength for two reasons. Firstly, their ease of application closely aligns with the training context in gymnastics. Secondly, the minimal similarity between the elements of motor task execution (handstand) and the tests was a decisive factor (Thorndike and Woodworth, 1901a,b,c)— this lack of similarity further challenges the study's hypothesis. If the elements of motor task execution (handstand skill) and the tests were more alike, the capacity to perform the handstand could influence the results.).

We collected data at the university laboratory, with standard lighting and windows covered adequately by curtains. To perform the kinematic analysis of handstand skills, we used a video camera (Nikon, D-750 Sigma - lens 17-50mm) with a 60 Hz frame rate and the Kinovea software (v.0.8.15) to analyze the data. We utilized a 2 kg medicine ball and measuring tape to administer the explosive force test on the upper limbs. The Maximum force test was conducted using a manual dynamometer (SGODDE, SKU), while a mat and a stopwatch (iPhone 5s cell phone) were employed for the Resistance force test. Additionally, two mattresses measuring 1.2 cm x 60 cm x 4 cm were positioned in front of the participant to mitigate the risk of potential frontal falls. Additionally, two researchers stood near the performers to ensure their safety.

Volunteers were marked on the right side of their bodies with red adhesive tape in the shape of the plus symbol (+) in the following locations: lateral condyle (knee), greater trochanter (hip), humeral head (shoulder), styloid process (hand) and the temporal bone (head). After placing landmarks, the volunteers received the following instructions: To perform the handstand skill, you must remove your feet off the ground while maintaining support with your hands and straighten your arms, legs, and spine as much as possible. You must touch the ground with the extended fingers and place the hands apart at shoulder width. The legs must remain together and upright, while the head must remain aligned with the body.

Furthermore, we showed each participant an image of the ideal task execution and subsequently played a video of an ideal execution pattern (performed by a professional) twice. Each individual was then required to make three attempts to familiarize themselves with the movement. Then, we instructed the participants to stay ready on the mattress and to initiate the movement only after the verbal command. Each participant performed three trials.

For the video analysis, we configured three angles using Kinovea. (Figure 1): (i)

Angle between the Patella and the Iliac crest; (ii) Angle between the Iliac crest and the Ulna; (iii) Angle between the Iliac crest and the Temporal bone. We selected the model based on a gymnast with over ten years of experience and participation in world artistic gymnastics (Rohleder & Vogt, 2018).

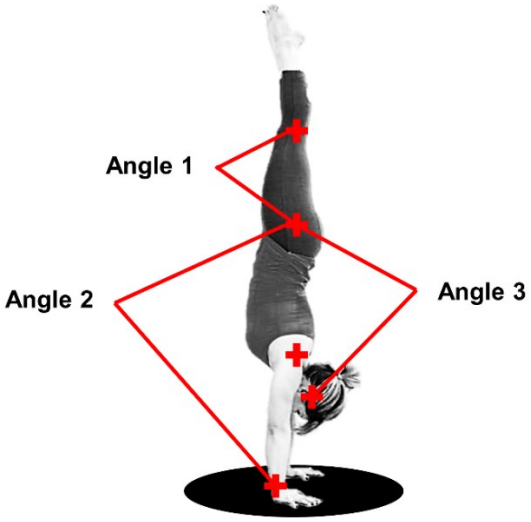

Figure 1. Angles analyzed.

Before the Explosive force test (Medicine-ball test), we demonstrated the participant's movement ("hold it close to the chest with the elbows flexed"). Then, the participants positioned themselves in the indicated location and threw the ball. After the familiarization procedure, the participants received the verbal command, "Throw the ball as far as possible, keeping their backs against the wall!". The distance reached was measured after identifying where the medicine ball touched the ground. Each participant performed three trials.

For the Maximum force test (Upper limb grip strength), participants were seated on a chair with their shoulders and hips aligned against the backrest. The hand holding the dynamometer remained with the palm facing the body, while the other hand rested over the leg opposite to the hand that held the dynamometer. Before conducting the test, we demonstrated the correct execution. At the verbal command of the experimenter, the volunteers held the dynamometer and performed the test while another experimenter registered the values obtained. The procedure was repeated by alternating the hands after 30-second intervals, involving three trials for each hand.

We used the Push-up test (Resistance force test) to measure the Resistance force. To conduct the test, the individual assumed a prone position with their hands placed slightly wider than shoulder-width apart and aligned with the chest. For males, the body formed a straight line from head to heels, with the feet together or slightly apart. Females positioned their knees on the ground and placed their hands 10 to 20 cm apart from the shoulder line. Upon a signal to begin, the individual lowered their body by bending their elbows until their chest touched the ground, ensuring the body remained straight throughout the movement. Then, they pushed their body back up to the starting position by extending their arms, completing one full repetition. We instructed

them to perform as many correct executions as possible within 30 seconds.

We analyzed the explosive force test of the upper limbs by using the mean score of the three trials, while we analyzed the maximum force test by considering the maximum value attained with each hand on the manual dynamometry. For the Resistance force test, we computed only the correct executions.

Motor performance was measured by the absolute error: the difference in the three angles produced by the model and the three angles produced by the performer (Rohleder & Vogt, 2018). The angle error was obtained using the following equation:

absolute error = $|a1_{goal} - a1_{real}| + |a2_{goal} - a2_{real}| + |a2_{goal} - a2_{real}|$

where a_{1goal}, a_{2goal}l, and a_{3goal} represent the model's values, and a_{1real}, a_{2real}, and a_{3real} denote the values obtained by the performer during the attempt.

The four predictor variables (explosive force, maximum force right-hand, maximum force left-hand, and resistance force) entered into the logistic regression were used to train the machine learning model (Naive Bayes classifier) (Webb et al., 2005). These machine-learning approaches determine the most probable outcome associated with a given set of predictor variables (Kononenko, 2001; Bunker & Thabtah, 2019). The value related to the performance in the task (absolute error) does not indicate class, just the absolute value of error. So, firstly, we determine the outcomes in classes and classify the absolute error into two classes: above average or below average [(value > 74.5: above average), (value < 74.5: below average)] (Figure 2).

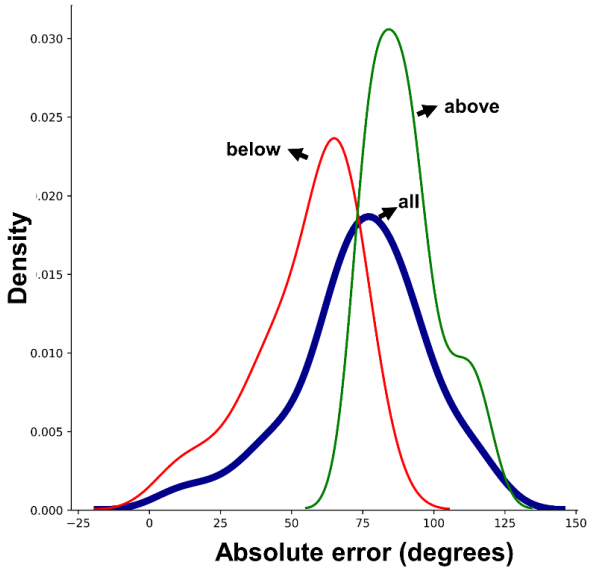

Figure 2. Histogram of the density of class above average, below average, and all interval

.

After classifying the data, we trained the machine learning model using ten folds and cross-validated it (Stratified K-Fold and Shuffled). The machine learning data was analyzed through the mean of accuracy in all folds, with values closer to 1 indicating that predictor variables explain well. Finally, we used the parameters of the train machine learning model to compare the absolute error actual (y_actual) and the predicted absolute error (y_predicted) and indicated the coefficient of determination (R^2) of comparison.

A linear regression test used motor performance (absolute error) and strength tests (explosive force, maximum right-hand,

maximum left-hand, and resistance force). We chose an alpha level of .05 for all inferential statistics. We calculated the effect sizes using Cohen's (*f2*). In this study, we adopted 0.02 as indicating a small effect size, 0.15 as a medium effect size, and 0.35 as a large effect size.

RESULTS

Figures 3 display the correlation matrix (A) and confusion matrix (B). All regression coefficients (Pearson) showed positive values, indicating that all relationships between predictor variables (explosive force, maximum force right-hand, maximum force left-hand, and resistance force) and absolute error are proportional (Figure 3A). The confusion matrix exhibited a high error rate in classifying the absolute error into two classes, above average and below average (Figure 3B). The mean accuracy of the machine-learning model was 0.44.

When we compared the data simulations of 32 subjects (using the parameters of the model trained) to the actual data, the R^2 was 0.22 (Figure 4).

Figure 5 displays the results regarding motor performance and the Explosive force test of the upper limbs. The regression test did not detect significant differences [$F(1,30) = 3.36$, $p = 0.07$, $R^2 = 0.10$, $f2 = 0.11$].

Regarding motor performance and the Maximum force test (right-hand), the regression test did also not detect significant differences[$F(1.30) = 1.70$, $p = 0.20$, $R^2 = 0.05$, $f2 = 0.25$] (Figures 6).

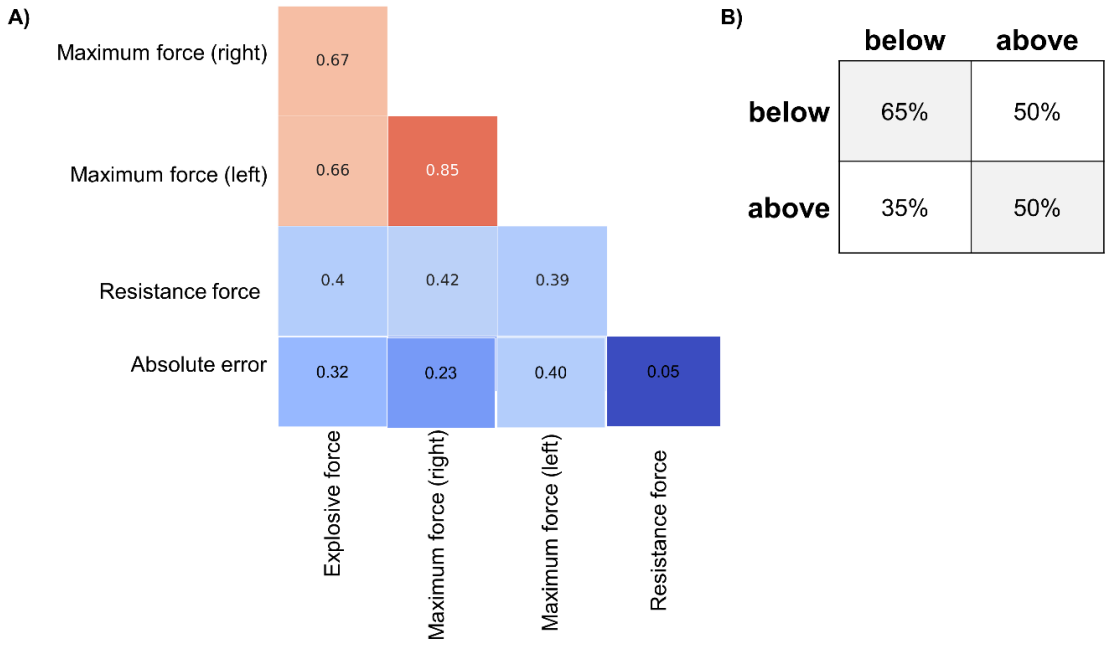

Figure 3. Correlation matrix (A) and confusion matrix (B).

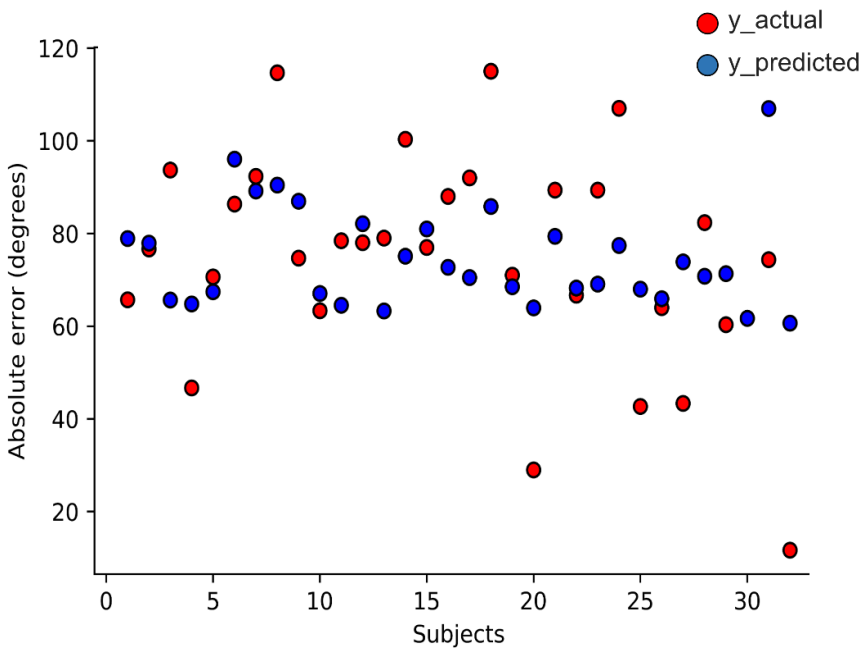

Figure 4. Data simulates of 32 subjects and the actual data.

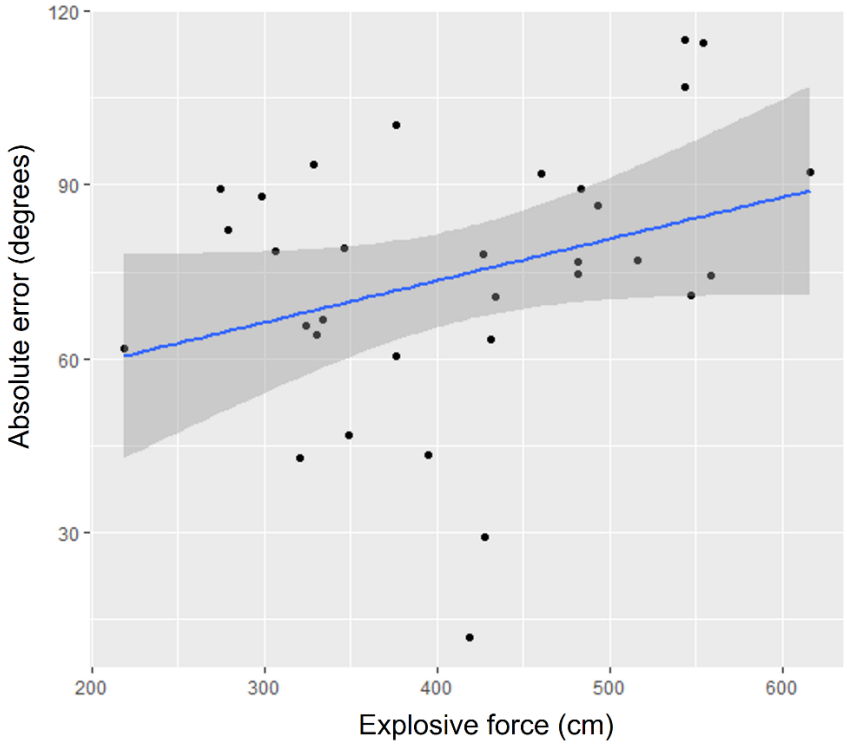

Figure 5. Linear regression: absolute error and explosive force.

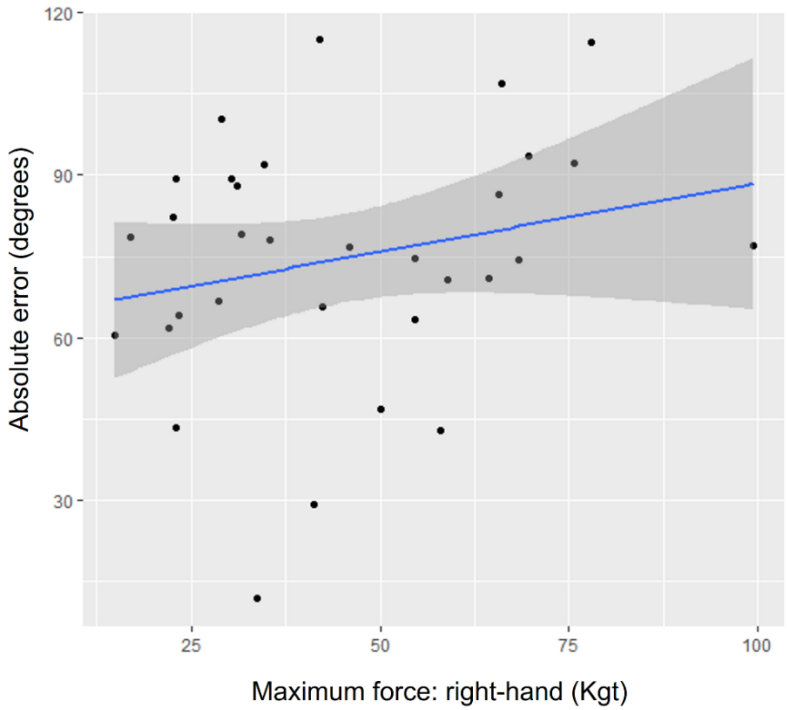

Figure 6. Linear regression: absolute error and maximum force (right-hand).

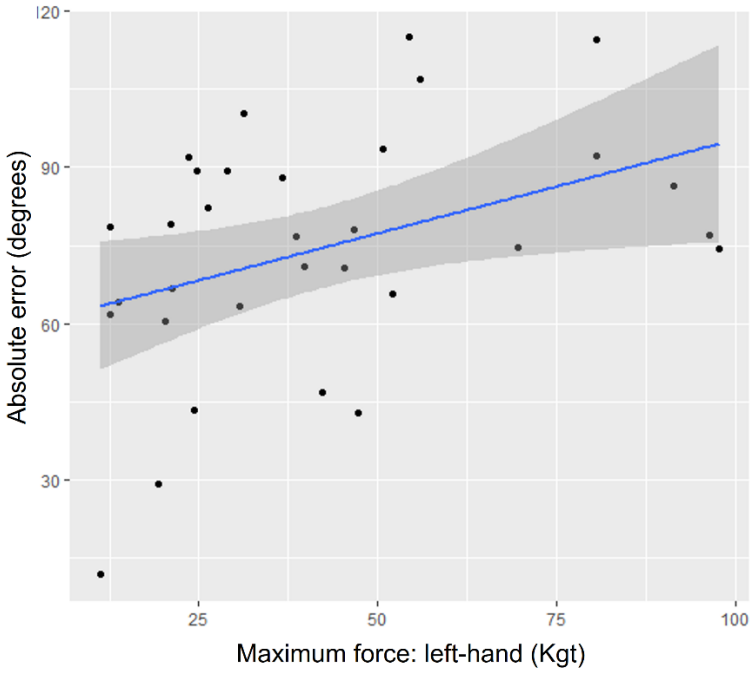

Figure 7. Linear regression: absolute error and maximum force (left-hand).

However, the regression analysis revealed significant differences in motor performance and Maximum force test (left-hand) [$F(1,30) = 5.59$, $p = 0.02$, $R^2 = 0.15$, $f2 = 0.17$], suggesting that error values in the motor task can be positively predicted based on the level of strength achieved in the handheld dynamometry (Figures 7).

Additionally, the regression test did not detect significant differences between motor performance and the Resistance force test [$F(1,30) = 0.08$, $p = 0.76$, $R^2 = 0.00$, $f2 = 0.00$] (Figures 8).

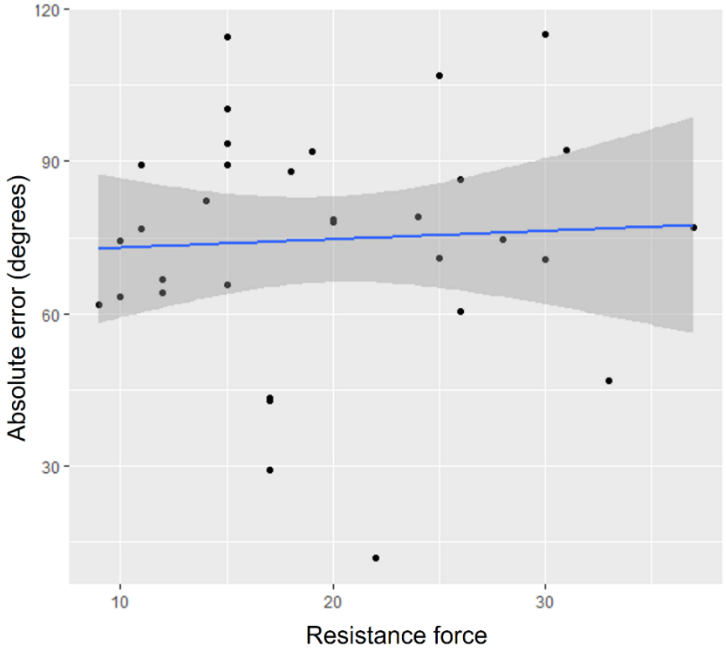

Figure 8. Linear regression: absolute error and Resistance force.

DISCUSSION

The aim of the present study was to explore the connection between strength capacity and motor performance in the gymnastic handstand, utilizing machine learning models and linear regression. It was anticipated that levels of strength capacity would predict the attained level of motor performance in the gymnastic handstand skill. However, our results did not corroborate the proposed hypothesis. The machine learning model revealed a weak relationship between strength capacity and motor performance. Furthermore, upon analyzing various forms of force manifestation (explosive, maximum, and resistance) alongside motor performance, we did not find evidence to support the hypothesis regarding the relationship between strength capacity and motor performance.

As previously mentioned, three distinct perspectives in the literature have been proposed to elucidate the relationship between motor performance and capacity. The first perspective suggests the existence of a general capacity that could underlie success in any motor task (McCloy, 1934; Hands, McIntyre, & Parker, 2018). The second perspective posits that performance may be contingent upon the specificity of the task (Lage et al., 2017; Robin et al., 2005; Tremblay & Proteau, 1998). The third perspective underscores the intricate interplay among task demands, environment, and individual factors (Newell, 1985; 1986).

Our results indicate a lack of a linear relationship between strength capacity and gymnastic handstand skill, implying that individuals with greater strength do not necessarily demonstrate superior performance in the skill. Contrary to the notion of a general capacity, motor responses within the environment do not appear to rely solely on a single motor capacity but rather on specific motor capacities or the dynamic interaction

between task, environment, and individual characteristics.

Studies involving postural control (Kiss et al., 2018) and strength analysis (Berger, 1962) have reported similar findings. Even skills often considered "generic," such as coordination and agility, have been demonstrated to be specific to certain motor tasks (Henry, 1968). Moreover, other research has emphasized the crucial role of the interaction between various components, including cognitive aspects, in the successful execution of motor skills (Robertson et al., 2004; Roca et al., 2011). The capacities examined in this study represent one of these components, suggesting that possessing a high level in only one capacity may not suffice to ensure favorable outcomes across different motor tasks. Therefore, elevated levels of strength may not guarantee overall success in tasks that involve different components.

An intriguing finding in our study was the relationship between maximum left-hand grip strength and motor performance. Our results indicated that increased maximum left-hand grip strength is associated with poorer performance. Conversely, the right hand exhibited no significant relationship between maximum grip strength and motor performance. This disparity between hands and its correlation with motor performance can be elucidated by the inherent asymmetry between the upper limbs (Fernandes et al., 2018). In certain skills, particularly those involving bimanual coordination like the handstand skill, upper limb asymmetry may indicate inferior performance (Santos et al., 2017; Sanders et al., 2011). In the realm of gymnastics specifically, there are indications that asymmetry negatively impacts motor performance (Batista et al., 2019). However, this assertion warrants further investigation with a more targeted research design.

A potential limitation of the study was the omission of strength values normalized by participant mass or height. Future studies are advised to incorporate parameters for result normalization. Another potential limitation was the degree of fit of the regression model (R^2) and the effect size, both of which were low. Two primary factors may account for these results. Firstly, the number of participants could be a limiting factor. The sample size affects measures such as regression model fit and effect size (Nakagawa and Cuthill, 2007), thus increasing the sample size is recommended for future studies. Secondly, there may be more complex and nonlinear dynamics among the study variables and other elements influencing motor response. These results suggest that even when significant relationships exist, the magnitude of the relationships between variables may be low. It is possible that more complex dynamics among other elements, besides strength capacity, contribute to motor response in the environment (motor output). In a sense, these results challenge our hypothesis but support the study's main finding.

CONCLUSIONS

Our study aimed to investigate the relationship between strength capacity and motor performance in gymnastic handstands using machine learning models and linear regression. Contrary to our initial hypothesis, our results did not provide support for a linear relationship between strength capacity and motor performance. This challenges the idea of a generalized capacity influencing success in motor tasks. Rather, our findings imply that motor performance is contingent upon specific capacities or the interplay of various factors,

including task specificity, environmental factors, and individual characteristics.

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WOMEN'S ARTISTIC GYMNASTICS IN BRAZIL: PATHS TAKEN FROM 1966 TO 2021

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Abstract

Brazilian men's and women's Artistic Gymnastics (AG) has been in the spotlight due to the results of some outstanding athletes in the most important international competitions over the last 20 years. However, the development of this sport in the national context does not reflect these achievements. This article performs a critical analysis of Women's Artistic Gymnastics (WAG) in Brazil, reviewing the trajectory of the main gymnasts and their achievements in the World Championships and Olympic Games from 1966 to 2021, as well as relevant contextual facts during this historical period. Medals in major events have been won since 2001, with gradual and unstable growth, placing Brazil among the most prominent countries. Nevertheless, the data suggest that the achievements were based on concentrated investment in elite gymnasts, mainly in the Olympic team, with the support of already established clubs. The development is still centralized in a few clubs, without showing a sustainable increase in the number of clubs and gymnasts. In this scenario, there is a need for a long-term plan that can sustain the development of the national ecosystem (clubs, local competitions, provincial federations) across all age-group categories and in connection with the national teams.

Keywords: *Artistic Gymnastics, Brazil, Women, History.*

INTRODUCTION

The XXXII Summer Olympic Games (OG), held in Tokyo in 2021, marked a significant milestone in the history of Brazilian Women's Artistic Gymnastics (WAG). Millions of Brazilians watched as gymnast Rebeca Andrade won a silver medal in the all-around final and a gold medal in the vault final. This achievement came 20 years after the first medal was won by a Brazilian gymnast at a World Championship.

Immediately after the Olympic medal became a reality, the mass media reported that Rebeca Andrade's medals were not merely an individual achievement but the culmination of efforts forged over many years by numerous gymnasts and their coaches. Rebeca Andrade's Olympic

success represented, in many ways, a collective accomplishment. Daniele Hypolito, who won the first Brazilian medal at the World Championships in 2001, encapsulated this sense of collective effort by saying,

"We needed this medal so badly, especially to be sure that we had been doing the right thing all these years, although the results were hard to come. It takes time, it was hard, it was arduous, but all the work done in all these years, at that moment, we could see that it was worth it" (Mello, 2021, n.p).

So, since Claudia Magalhães who was the first Brazilian gymnast at the Olympic Games in Moscow 1980, to the memorable medals won by Rebeca Andrade in Tokyo 2020, Brazil has been represented by several talented gymnasts. These athletes have experienced tremendously different realities, especially with regard to training conditions and financial support. Recognizing the importance of its predecessors, Rebeca Andrade said,

"[...] I went through a lot and set these Olympic Games as a goal, but my goal here was to do my best, to shine, and I think I did: I got our first Olympic medal in WAG. [...] All the women who competed for Brazil in this sport sees themselves in this medal, they are very proud of me and feeling proud of this history (COB, 2021).

[...] I'm just taking this history one step further, and I hope our generation achieves that and much more. I'm very proud of myself and of all the people who helped me get here, since I could never have done it alone (CBG, 2021)."

After the euphoria and the well-deserved celebration of such an emblematic achievement, we returned to our studies regarding the national context of Women's Artistic Gymnastics (WAG). We immediately noticed how the Brazilian Gymnastics Federation (CBG) had achieved a new status nationally, placing itself on the same level as the national federations of traditional sports such as judo, volleyball, and sailing. Gymnastics seemed to be transitioning from an emerging sport to a consolidated one on the national scene.

However, different studies showed that despite the medals that have been won at Worlds and Olympic Games, the national development of Women's Artistic Gymnastics (WAG) in Brazil revealed inconsistencies. These inconsistencies are characterized by a reduced number of athletes and clubs, which are concentrated in only a few states. Most training facilities lack adequate equipment and multidisciplinary teams. Additionally, there is a scarcity of qualified coaches, with many migrating to other countries (Lima, 2016). Thus, contrary to the results achieved by Rebeca Andrade and the positive media discourse, Brazilian WAG has indicators that point to an incipient level of development, as suggested by Bortoleto and Schiavon (2018).

A similar situation was observed by Oliveira (2010) in Men's Artistic Gymnastics (MAG). According to this study, the international achievements were not aligned with the development of this gymnastics discipline nationally. In fact, "for a long time the talent and effort of our gymnasts and coaches have stood out in the face of adversity that marked the amateurism of this discipline" (Oliveira & Bortoleto, 2009, p. 308).

[…] the recent and significant international results obtained by Brazilian gymnasts do not match the sport reality, i.e., they are not the result of excellent conditions gained by federation, infrastructure, number clubs, among others, but rather of excellent performance of individual talent (Oliveira, 2010, 38).

Based on these preliminary arguments, this study aimed to conduct a critical analysis of the development of Brazilian Women's Artistic Gymnastics (WAG) from 1966 to 2021. The analysis involved reviewing the results obtained in World Championships (WC) and Summer Olympic Games (OG) and discussing the contexts in which these results were achieved. These events were chosen due to their representativeness and importance in the context of Artistic Gymnastics (AG), especially as they include the most prominent countries and gymnasts, and establish benchmarks for national teams (Oliveira & Bortoleto, 2009).

METHODS

This study analyzes the participation of Brazilian Women's Artistic Gymnastics (WAG) in World Championships (WC) and Olympic Games (OG) from 1966 to 2021 through a qualitative approach. For this purpose, a narrative literature review was employed. Narrative literature reviews describe and discuss specific topics from theoretical and contextual perspectives (Allen, 2017). According to Allen (2017), "A narrative literature review provides a synthesis or examination of the literature by considering issues and the development of the research over time" (p. 1075).

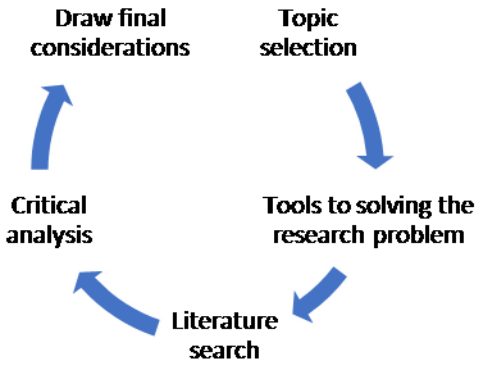

Figure 1. Research process.

Considering the time frame and the amount of data, the analysis was distributed into four periods based on Schiavon's proposal (2009):

- 1966 to1992 - Pioneer period in international competitive scene: first participation in world championships and Olympic Games, precarious training and support conditions for Brazilian gymnasts;
- 1993 to 2000 - Organizational structuring period: period of development of the Brazilian Gymnastics Confederation (CBG - first headquarters), training structure and funding for the sport in Brazil;
- 2011 to 2008 - Centralized training system of permanent national team: beginning and end of the permanent national team; first international podium results and establishment of international training conditions;
- 2009 to 2021 - Decentralization and establishment of training camps: end of the Brazilian permanent national team; hosting of mega-events in Brazil (Pan American Games, Summer Olympic Games, etc), consolidating international achievements. First Olympic medals in Brazilian WAG.

The data were obtained from records of WAG participation and results in WC and OG, combining information from online sources (newsletters, magazines, minutes) and other hard copy documentary sources (books, scientific articles, etc.). The competition results were collected from the International Gymnastics Federation (FIG) official web in combination to Nestor Soares Publio's books (Publio, 2002; 2006). Additional data, as suggested by Molinari *et al.* (2018), obtained at the Brazilian Gymnastics Federation (CBG) and the Brazilian Olympic Committee (COB) webs were used.

Data were analyzed descriptively, creating a logical and critical timeline with the main facts, events, precursors, similarities, differences and results obtained in each analyzed period. The quantitative data were treated using descriptive statistics (Appolinário, 2006).

RESULTS AND DISCUSSION

1966-1992 – Pioneer period in international competitive scene

During this period, Brazilian Women's Artistic Gymnastics (WAG) relied primarily on the efforts of gymnasts, coaches, and their families, with minimal support from sports institutions, including clubs and the Brazilian Gymnastics Federation. It's important to note that, until 1978, Artistic Gymnastics was subordinated to the Brazilian Sports Federation and coordinated by the Council of Gymnastics Advisors. This meant that Artistic Gymnastics was affiliated with an eclectic federation of sports and had to share the spotlight with disciplines that received greater government and public interest, such as soccer.

Schiavon (2009) refers to the gymnasts of this period as "pioneers" because they were the first representatives of Brazil in World Championships (WC) and Olympic Games (OG). The author highlights that these gymnasts regularly faced "situations of low training support regarding financial, material, and human resources" (Schiavon, 2009, p. 176).

The gymnast Marion Faedrich Dullius was the first Brazilian gymnast to compete at the World Championships, particularly at the 16th World Championship held in Dortmund, Germany, in 1966. Publio (2002) explains that Marion Faedrich Dullius competed alongside her husband, José Fabiano Dullius, who was the delegate and coach of Brazil at this event. Marion Dullius finished the competition in 148th place out of 156 participants.

It is worth mentioning that Publio (2002) suggested that Brazil could have already participated with women gymnasts at World Championships, specifically in 1954 in the city of Rome, Italy. The author describes a regrettable situation where Nilda Rosa did not travel because Brazilian delegates did not agree to change someone in the team so that Nilda's coach could accompany her, especially because she was a minor and could not travel without a companion. "It was known in advance that the men's team, even individually, would have no chance, and if Nilda went on that opportunity, she could have left a great impression, such was her high technical level" (Publio, 2002, p. 143).

These situations prompt reflection on gender issues in Brazil and how female gymnasts were affected in their development by them. Brazilian women did not have the full right to come and go, to own property, to divorce, and many other things until 1962 when the Married Women's Statute granted them full civil capacity (Htun & Welson, 2018). In the sports context, there was an

implicit order inhibiting the presence of women. Although gymnastics has come to be understood as a practice suitable for women (Oliveira et al., 2023; Oliveira, Souza & Nunomura, 2021), women gymnasts were impacted by the prevailing machismo at the time.

It is worth mentioning the translation of the Code of Points (CoP) by the Brazilian Sports Federation in 1972, which, according to Publio (2006), was one of the main factors that boosted the development of Artistic Gymnastics (AG) in Brazil during that period.

In 1973, some judging update courses were organized, and it is important to highlight the first participation of Brazilian women in a FIG Judges Course (Publio, 2002). Also, in the same year, Publio (2006) mentions a gymnastics tour featuring the best world-class gymnasts in Brazil. Coordinated by the FIG, besides encouraging the practice of the sport, the organizers brought eight complete sets of official equipment. These equipment sets remained in Brazil and were a fundamental resource for the development of the sport at that time. Until now, Brazil does not have a FIG-approved apparatus manufacturing company.

Subsequently, Brazil would only compete again at the World Championships two editions later, in 1974, when the competition took place in the city of Varna, Bulgaria, with the gymnasts Gisele Radomsky, Silvia Pinent, and Eneida Flecha representing the country.

According to Publio (2006), the first signs of progress in AG in Brazil began to be seen with invitations for Brazilian gymnasts to participate in international events, such as the American Cup in 1976. The "I Intercontinental Course" for FIG judges, held in Rio de Janeiro in 1976, certainly contributed to the development of AG judging in Brazil (Publio, 2006).

In 1978, the year that marked the foundation of the Brazilian Gymnastics Federation, Brazil competed for the first time at the World Championships with a full team of six gymnasts, finishing the competition in 19th place in Strasbourg, France. The team was composed of Lilian Carrascozza, Maria Cristina Coutinho, Silvia R. P. Anjos, Cláudia Magalhães, Marian Fernandes, and Gisele Radomsky. It is important to highlight that Lilian Carrascozza received Brazil's first world-class gymnast brevet, awarded by the FIG to gymnasts with an average of nine points in all events when the highest score was 10 points (Publio, 2002).

Brazil has made great progress since its first participation in 1966 to 1978. In fact, according to Publio (2006, p. 224) the period from 1950 to 1978

> […] was a productive period, both in organization and participation in championships, as well in educational courses. The encouragement to organize events for young gymnasts was key to AG development. […] All the work done in those years resulted in relevant technical development, which led to an increase in the number of gymnasts who had significant participation in international events.

More specifically, during this period, the state federations of São Paulo and Rio Grande do Sul invited national and foreign coaches to develop gymnasts and coaches. Georges Chautemps (France), Takehisa Ishihara (Japan), Hideaki Kurihara (Japan), Enrique Rapesta (Argentina), and Sigfried Fischer (Brazil) are examples of this initiative. It's important to highlight that the Brazilian Ministry of Education and the Brazilian Sports Federation also supported national courses aimed at instructing

coaches about compulsory exercises and teaching processes in all apparatuses (Publio, 2002).

The foundation of the Brazilian Gymnastics Federation in 1978 undoubtedly boosted the development of Artistic Gymnastics in Brazil. According to Hugo Coelho de Almeida, former vice-president of this entity, the history of Brazilian gymnastics started at that moment (Publio, 2002). It's a strong statement because we know that the sport has already been on a path of development, but it's understandable given the step taken with the foundation of the federation.

In 1979, at the pre-Olympic World Championships held in Fort Worth, USA, Brazil was represented by a full team composed of six athletes. Brazil finished the competition in 23rd place among 27 teams. Publio (2002) points out that Cláudia Magalhães qualified for the 1980 Olympic Games in Moscow, which was unprecedented (Publio, 2002).

With the US boycotting the Moscow Olympic Games, Cláudia Magalhães qualified for the individual all-around final (CII), which gathers the best gymnasts in the sum of the four apparatuses, and finished 31st (Carvalho, 2007; Oliveira, 2014).

In 1980, the "Gold Medal Project" was launched in Rio de Janeiro, sponsored by a private school named *Colégio Impacto* and supported by Brazilian Gymnastics Federation, presided over by Mr. Siegfried Fischer. For the first time ever, a specific AG training center was set up in Brazil, including a multidisciplinary team of professionals and some Russian coaches in order to provide high quality training for a selected group of gymnasts. We did not have access to the participating gymnasts' names, and "although the project was not successful, it served as a benchmark for future national projects" (Publio, 2006, p. 224). Schiavon (2009), based on Tatiana Figueiredo's testimony, a gymnast that took part in this project, reported that the best gymnasts in the country were gathered to join the project. Coaches, psychologists and physicians were hired, and the project lasted around a year and a half. Short-term projects like this one cannot produce significant changes in the sport's development, but this was certainly an initiative that influenced its development, as we will see later.

In the following World Championships held in Moscow in 1981, Brazil finished the team competition in last place out of 19 competitors. In the 1983 edition in Budapest, the team finished in 22nd place among 28 teams. Gymnast Tatiana Figueiredo qualified for the Los Angeles Olympic Games in 1984 and was awarded the FIG brevet together with Jacqueline Pires.

Placar Magazine (1984) mentioned that Tatiana Figueiredo had no expectations of achieving a great result in Los Angeles, especially since she had finished 95th at the World Championships in Budapest. She was confident only in her vault score but feared the balance beam and the political judgment of judges. During the 1984 Olympic Games, boycotted by the Soviet Union, Tatiana Figueiredo didn't advance to finals and ended the competition in 56th place out of 62 participants.

In the following World Championships in 1985, the best Brazilian gymnast was Tatiana Figueiredo, who finished the event in 66th place in the individual all-around. The Brazilian team finished in 20th place among 23 nations entered in the competition. At the pre-Olympic World Championships in 1987, another gymnast from Rio de Janeiro, Luisa Parente, obtained FIG brevet and finished the competition in 82nd place. The team finished the qualification round in

21st place among 31 teams. In this competition, Luisa Parente also earned qualification to represent Brazil in the Olympic Games in Seoul (1988).

In Seoul, Luisa Parente qualified for the all-around final in 33rd place. Publio (2002) considers that Luisa Parente deserves credit for achieving this feat in an Olympic competition without boycotts. However, she ended the final in 34th place.

The 1989 World Championships took place in Stuttgart, Germany, where Brazil was represented by a full team that finished in 21st place. The best Brazilian gymnast ended the qualification round in 106th place. Notably, Luisa Parente, the top gymnast in Brazil at that time, did not compete in the floor exercise optional routine, which contributed to these less favorable results.

In Indianapolis, United States, where the 1991 World Championships were held, the Brazilian team finished the competition in last place among 28 participating teams. Once again, Luisa Parente secured an Olympic berth. However, in Barcelona, she failed to qualify for finals and finished the competition in 57th place out of 92 gymnasts entered.

Table 1
Brazilian gymnasts attending OG and WC from 1966 to 1992 and the state they represented.

EVENT	GYMNASTS REPRESENTING BRAZIL
1966 WC	Marion Faedrich Dullius (RS)
1974 WC	Eneida Flecha (RS), Gisele Radomsky (RS), Silvia Pinent (RS)
1978 WC	Cláudia Magalhães (RJ), Gisele Rodomsky (RS), Lilian Carrascozza (RJ), Maria Cristina Coutinho (RJ), Marian Fernandes (RJ), Silvia dos Anjos (RJ)
1979 WC	Altair Prado (RJ), Cláudia Magalhães (RJ), Jacqueline Pires (RJ), Lilian Carrascozza (RJ), Marian Fernandes (RJ), Silvia dos Anjos (RJ)
1980 OG	Cláudia Magalhães (RJ)
1981 WC	Altair Prado (RJ), Carine Leão (RS), Cláudia Magalhães (RJ), Denilce Campos (RJ), Jacqueline Pires (RJ), Lilian Carrascozza (RJ)
1983 WC	Altair Prado (RJ), Cláudia Magalhães (RJ), Denilce Campos (RJ), Jacqueline Pires (RJ), Marian Fernandes (RJ), Tatiana Figueiredo (RJ)
1984 OG	Tatiana Figueiredo (RJ)
1985 WC	Altair Prado (RJ), Elena Fornogerakis (SP), Jacqueline Pires (RJ), Marian Fernandes (RJ), Tatiana Figueiredo (RJ), Vanda Cristina Oliveira (SP)
1987 WC	Luisa Parente (RJ), Margaret Yada (RS), Marian Fernandes (RS), Priscilla Steimberger (RJ), Tatiana Figueiredo (RJ), Vanda Cristina Oliveira (SP)
1988 OG	Luisa Parente (RJ)
1989 WC	Adriana Andrade (RJ), Ana Paula Luck (RJ), Anne Fernandes (RJ), Daniela Mesquita (RJ), Luisa Parente (RJ), Margareth Yada (RS)
1991 WC	Luisa Parente (RJ), Débora Biffe (SP), Marina Fagundes (SP), Anne Fernandes (RJ), Viviane Cardoso (RJ) (did not compete), Adriana Andrade (RJ) (did not compete).
1992 WC	Luisa Parente (RJ), Débora Biffe (SP), Viviane Cardoso (RJ)
1992 OG	Luisa Parente (RJ)

Source: Adapted from Publio (2002). *Rio Grande do Sul (RS), Rio de Janeiro (RJ) and São Paulo (SP).

Analyzing this period, we observe that gymnastics was already a much more structured sport by the time the Brazilian Gymnastics Federation was founded. Vieira and Freitas (2007) note that exchanges with other countries for the acquisition of equipment and technical expertise were already a reality. We concur with these authors that "all these factors combined led to more frequent participation by Brazilian

gymnastics in international tournaments, and in 1980, they were finally able to make their debut at the Olympic Games" (Vieira & Freitas, 2007, p. 30).

Throughout the 1980s, only a few organizations developed AG projects, and those that did often provided inadequate training conditions for high-performance athletes. Inadequate infrastructure and facilities were prominent aspects of this historic moment, making long-term development slower and more challenging (Oliveira & Bortoleto, 2009; Lima, 2020). It is important to remember that Brazilian gymnasts faced significant difficulty adapting to the equipment used in international tournaments, as they trained with inferior and often inadequate equipment in Brazil (Oliveira & Bortoleto, 2009). Irregular and insufficient funding persisted throughout the 1980s and early 1990s.

[…] they also had limited exchanges and participation in international events, which is of paramount importance in high-level sports. With the restricted possibility of participating in exchange programs and competing abroad, the gymnasts had lower chances of winning medals due to the lack of experience and being unknown to judges (Oliveira & Bortoleto, 2009, p. 305).

This situation certainly influenced the performance of Brazilian gymnasts in international championships. However, the participation of "pioneers" gymnasts was extremely important to boost the development of this sport discipline in Brazil (Schiavon, 2009; Costa, 2018). In that regard,

The initiatives and support of the São Paulo Gymnastics Federation, Brazilian Gymnastics Federation and Education Ministry led to better qualifications of coaches who had the possibility to gain experience in the best gymnastics centers in the world and update their knowledge, which certainly had an impact on the following generations and boosted AG in Brazil (Schiavon et al., 2013, p. 425).

Despite all the difficulties faced during the period of 1966 to 1992, Brazilian coaches improved their skills mainly through international exchange programs and courses given by foreign coaches in Brazil (Oliveira & Bortoleto, 2009). The arrival of foreign coaches was also important for the development of coaches and, consequently, gymnasts. Oliveira *et al.* (2023) affirm that since the introduction of AG in Brazil until today, foreign coaches contributed to the development of gymnasts, especially those who achieved historic results for the country.

In the period of 1978 to 1992, AG in Brazil had amateur features that prevented its full development. Nuzman (1985) mentions that projects lacking sequence and continuity, marked by improvisation and a lack of financial resources, were characteristics of Brazilian sport amateurism back then, relying on volunteer work.

In fact, the Brazilian Gymnastics Federation survived this period without its own headquarters and with scarce funding (Oliveira, 2010). From its foundation in 1978 until 1991, it had three elected presidents: Siegfried Fischer (1979 – 1985), Fernando Brochado (1985 – 1988), and Mário César Cheberle Pardini (1988 – 1991). The headquarters moved respectively to the states of Rio Grande do Sul, São Paulo and Minas Gerais (Bortoleto & Schiavon, 2018), looking for improvements although still with an amateur management and centralized in the south and southeast of Brazil.

1993-2000 – Organizational structuring period

During this period, Brazilian WAG also suffered from overall lack of funding, structure (facilities, equipment, etc.) and institutional support (Schiavon, 2009). Schiavon (2009, p. 176) calls the athletes of this period "transitional gymnasts" as they went through a phase " with poor support and structure, at a given moment, similar to what was experienced by the pioneer gymnasts; however, later they had the opportunity to experience a phase of greater support".

In this scenario, Luisa Parente continued to be the highlight of Brazil on the international stage. At the WC in Paris in 1992, Luisa Parente managed to reach two semi-finals, placing 12th on the uneven bars and 14th on the balance beam (Publio, 2002).

One of the protagonists of the period from 1993-2000 was Soraya Carvalho, who was the only representative of Brazil at the 1993 individual WC in Birmingham (England), where she ended the competition in 38th place. In the following year, 1994, Brazil didn't compete at the team WC held in Dortmund (Germany). Publio (2002) mentions that this absence ended a period of continuous attendance of Brazil with complete teams at WC, which started in 1978. The Brazilian women were represented by the judge Yumi Sawasato, who was invited by FIG to act as an expert in the vault event.

Also in 1994, FIG organized the individual WC in Brisbane (Australia). Following the individual apparatus competition, the best gymnast from Brazil was Letícia Iishi, who finished in 34th place on floor exercise and balance beam. In the AA, the best-ranked Brazilian was Adriana Silami, who ended in 53rd place (Publio, 2002).

In Japan, more precisely in the city of Sabae, the Brazilian women finished 21st in the team competition at the 1995 World Championships out of 26 participating teams. The gymnast Soraya Carvalho earned the FIG brevet of world-class gymnast and qualified for the 1996 Atlanta Olympics (Publio, 2002). Soraya Carvalho qualified for the AA final in Sabae and finished in 35th place (USA Gymnastics, 2023). With this result, Soraya Carvalho became the first Brazilian gymnast to compete in the AA final in WCs.

In the Olympic year of 1996, FIG organized a WC with a format similar to that of 1992, with medals being awarded only in apparatus competitions. In San Juan (Puerto Rico), Brazilian gymnast Soraya Carvalho advanced to the balance beam semi-final and narrowly missed a spot in the final by 0.087 points, finishing the competition in 9th place on this apparatus.

Unfortunately, despite the good results obtained in San Juan, she was unable to compete in the 1996 OG in Atlanta (USA) due to an injury days before the competition started, leaving Brazil with no representatives in this Olympic edition (Carvalho, 2007; Schiavon, 2009). It's important to highlight that the result achieved at the Puerto Rico WC ranked Soraya among the favorites on the balance beam in Atlanta.

In 1997, only two gymnasts represented Brazil at the WC in Lausanne (Switzerland), where Mariana Gonçalves finished in 48th place and Patrícia Aoki in 84th. This event only had individual competitions. Two years later, in Tianjin (China), an unprecedented event in Brazilian WAG occurred: the qualification of two Brazilian gymnasts to compete in the

2000 Sydney Olympics (Oliveira & Bortoleto, 2009).

Daniele Hypolito and Camila Comin were selected to represent Brazil in Sydney. Schiavon (2009) considers this the beginning of a rise that would be consolidated in the following period. The gymnast Daniele Hypolito qualified for AA and finished in 20th place, the best result by a Brazilian female gymnast in the Olympic Games until then (Schiavon, 2009)..

Table 2
Gymnasts who represented Brazil in OG and WC from 1993 to 2000, and the state they represented.

EVENT	GYMNASTS REPRESENTING BRAZIL
1993 WC*	Soraya Carvalho (RJ)**
1994 WC	Adriana Silami (RJ), Letícia Ishii (SP), Silvia Mendes (RJ), Soraya Carvalho (RJ) (did not compete)
1995 WC	Soraya Carvalho (RJ), Liliane Koreyasu (RJ), Beatrice Martins (RJ), Letícia Ishii (SP), Mariana Gonçalves (SP), Beatriz Degani (SP), Melissa Sugimote (SP)
1996 WC	Beatrice Martins (RJ), Letícia Ishii (SP), Mariana Gonçalves (SP), Soraya Carvalho (RJ)
1996 OG	Soraya Carvalho (RJ) (did not compete)
1997 WC	Mariana Gonçalves (SP), Patrícia Aoki (SP)
1999 WC	Camila Comin (PR), Daiane dos Santos (RS), Daniele Hypolito (RJ), Heine Araújo (RJ), Marília Gomes (SP), Stefani Salani (SP)
2000 OG	Camila Comin (PR), Daniele Hypolito (RJ)

Source: Adapted from Publio (2002). *CII (individual all-around) and CIII (individual apparatus) only. ** Rio Grande do Sul (RS), Rio de Janeiro (RJ), São Paulo (SP) and Paraná (PR).

Between 1993 and 2000, Brazilian athletes, clubs, and the Brazilian Gymnastics Federation itself still showed amateur management and a lack of regular investment in the sport (Oliveira & Bortoleto, 2009): "Such was the sport's amateurism that in the early 1990s, CBG documents were kept in the trunk of the car of then president Vicélia Florenzano, who took office in her first term in 1991" (Vicelli, 2008, apud Oliveira & Bortoleto, 2009, p. 305).

In 1995, while Vicélia Florenzano was still president, the Brazilian Gymnastics Federation succeeded in setting up its first official headquarters in Curitiba, state of Paraná, with support from the COB and the state government (Bortoleto, 2000; Nunomura & Oliveira, 2012). Later, in a new facility, in addition to the administrative offices, there was also a training center (TC) for high-performance gymnasts from 1997 (Nunomura & Oliveira, 2012). In 1999, the Center for Excellence in Gymnastics was installed at the CBG headquarters (Schiavon & Paes, 2012), enhancing the relevance of this project for national gymnastics:

The headquarters of the Brazilian Gymnastics Federation house the Center for Excellence in Gymnastics, with a highly developed infrastructure. It boasts official and auxiliary equipment distributed in two gymnasiums measuring sixty by thirty-six meters each, and a multidisciplinary team comprising Brazilian and foreign specialist coaches, physicians, physical therapists, psychologists, nutritionists,

choreographers, and coordinators who manage the demands of the permanent Brazilian teams of artistic (men and women), rhythmic and trampoline gymnastics (Carvalho, 2007, p. 25).

Therefore, from the early 1990s, a notable improvement in AG infrastructure was noted in Brazil (Schiavon & Paes, 2012). Nevertheless, "even with this better infrastructure, the Brazilian Gymnastics Federation's budget was still limited, and few athletes had personal sponsors. This situation lasted until the early 21st century" (Oliveira & Bortoleto, 2009, p. 306). Thus, we observe that the achievements in that period were based on talented gymnasts, well-prepared coaches, and better training conditions (Nunomura, 2004).

It is relevant to mention the arrival of the Ukrainian coach Iryna Ilyashenko in 1999, hired by the Brazilian Gymnastics Federation with the support of the Brazilian Olympic Committee and the International Olympic Committee (funds from the Olympic Solidarity Program) to be part of the coaching staff of the Brazilian national team from 1999 to 2001. She was responsible for preparing and introducing in Brazil a centralized training program at the Curitiba center for excellence from 2001, having important consequences at the national and international level for Brazilian WAG (Nunomura & Oliveira, 2012; Schiavon et al., 2013).

2001-2008 – Centralized training system of permanent national team

The period 2001-2008 brought major changes to Brazilian WAG based, for the first time on a national plan and on policies aimed to develop the national team. Despite having experienced a phase of poor support and structure, a few remaining gymnasts from the previous period took part in this one (Schiavon, 2009). In addition, we already observe the rise of new gymnasts who participated in the centralized training system: […] since their arrival at the national team, they found outstanding conditions for adequate preparation, equivalent with those of world powers in gymnastics that compete for medals at WC and OG (Schiavon, 2009, p. 177).

In this period, Vicélia Florenzano (1991 – 2009) remained the Brazilian Gymnastics Federation president, and it was under her administration that Brazil achieved important international results (Oliveira, 2007), including three of the six medals won at WAG WC until 2021.

In 2001, two years after the arrival of the aforementioned Ukrainian coach Iryna Ilyashenko, two other coaches from Ukraine, Oleg and Nádia Ostapenko, arrived in Brazil to complete the coaching staff of the now "permanent" Brazilian WAG national team, inaugurating a training system similar to sports boarding schools of the former Soviet Union, which lasted for two Olympic cycles at the Curitiba TC (Nunomura & Oliveira, 2012). Therefore, from 2001 the best gymnasts in the country started training together on a full-time basis, radically modifying the organization of the sport nationwide (Nunomura & Oliveira, 2012). Thus, even private clubs, started to cede their best gymnasts to the national teams based in Curitiba, a situation that afforded many benefits but also caused damage to the sport, as we will analyze later (Nunomura & Oliveira, 2012; Schiavon, 2009).

The positive development of Brazilian WAG in subsequent years was attributed to the infrastructure of the training center and the centralization of the national team in Curitiba: "[…] it brought uniformity to the team and contributed to the rapid rise of AG

in Brazil" (Nunomura & Oliveira, 2012, p. 380). The improvements made by the Brazilian Gymnastics Federation included the beginning of the professionalization of the administration carried out in its new headquarters and access to more public and private funding. The role of the training center established in Curitiba was crucial, and it happened thanks to the approval of the Agnelo/Piva Act in 2001, allocating lottery revenue funds to Olympic sports (Oliveira, 2010).

Maintenance of the physical infrastructure of the training center, periods of adaptation and exchange abroad, remuneration of the training staff consisting of Brazilian and foreign coaches, maintenance of the athletes and payment of the multidisciplinary staff to support the team were funded with resources from the Agnelo/Piva Act and the official sponsor of Brazilian Gymnastics Federation (Oliveira, 2010, p.160).

In addition to this support, the Brazilian Gymnastics Federation had resources from the Olympic Solidarity Program of the International Olympic Committee (IOC) which, according to the COB (2006b), paid the salaries of the head coach during the period of his stay in Brazil (Nunomura & Oliveira, 2012, p. 380).

The first WC of this period, the 35th World Championship in Ghent, Belgium (2001), already pointed to what would be a leap for Brazilian WAG. At that event, the gymnast Daniele Hypólito finished 4th in the individual all-around event, the country's best classification so far in WC. In addition, Daniele Hypolito and Daiane dos Santos qualified for the floor exercise finals, finishing 2nd and 5th, respectively (FIG, 2019). So, we have the first WAG WC medal for Brazil, silver in the floor exercise event, won by Daniele Hypólito. Oliveira and Bortoleto (2009) draw attention to the fact that even with improved infrastructure, the Brazilian Gymnastics Federation continued to have a limited budget and few athletes had personal sponsors. The author mentions that Daniele Hypólito traveled to Ghent with financial support given by soccer player Ronaldo because she didn't have the resources to support herself during the competition.

Daniele Hypólito remained among the best in the world in the 2002 WC in Debrecen, Hungary. This event only had individual competitions. Daniele Hypólito qualified for the floor exercise semifinals in third place. In the semifinals, Daniele Hypólito got the second-best score but ended in 5th place in the finals. She also advanced to the semifinal on vault and ranked 14th. A gymnast from the new generation, Caroline Molinari, advanced to the semifinal on uneven bars in 11th place, finishing the competition in 14th. These results showed that the success of Brazil in the previous WC was a product of consolidated work.

In 2003, at the pre-Olympic WC in Anaheim, USA, two Brazilians competed in the individual all-around final: Camila Comin finished 19th, and Daniele Hypolito finished 24th. At the same tournament, two achievements marked the history of Brazilian WAG: Daiane dos Santos won the first WC gold medal in the floor exercise, and Brazil finished 8th in the team final. For the first time ever, Brazil qualified a WAG team to compete in Olympic Games. As mentioned before, previously, Brazil had only been represented by individual gymnasts (FIG, 2019). In a way, these achievements point to the consolidation of the long-term work introduced and intensified in previous years (Oliveira & Bortoleto, 2009).

At the Athens Olympic Games in 2004, Camila Comin and Daniele Hypolito made it to the individual all-around final, finishing 26th and 12th respectively. Daiane dos Santos advanced to the floor exercise final as a favorite to win the gold medal but finished in 5th place, the best placement of a Brazilian in OG in this event so far. The Brazilian team finished in 9th place, not taking part in the CIV (team finals), in which only the best eight teams compete for medals (FIG, 2019). Regarding this period, Carvalho (2007, p. 25) points out that:

With the large investment in the Center for Excellence in Gymnastics, artistic gymnastics as a high-performance sport enjoys a particularly privileged moment, which was expressed by two unprecedented qualifications at the 2003 pre-Olympic World Championships (one of the most prestigious competitions in the sport for qualifying for the Olympic Games) in the city of Anaheim in the United States. The world history of the sport was marked there by the gold medal won by Brazilian gymnast Daiane dos Santos, and the remarkable qualification of the Brazilian women's artistic gymnastics team for the 2004 Athens Olympic Games.

During the 2005 WC in Melbourne, Australia, three gymnasts competed for Brazil. Daniele Hypolito earned a place among the top 10 gymnasts in the world by finishing the AA in 9th place. On the floor exercise, Daiane dos Santos ended the competition in 7th place. The format of this WC only included individual competitions.

In the subsequent pre-Olympic WC in Stuttgart, Germany, in 2007, Brazil stood out once again with a bronze medal in the individual all-around event won by Jade Barbosa. She also qualified for the finals in the vault (5th) and balance beam (7th) events. This was also the first and only individual WC all-round medal won by Brazil to date. In addition, Brazil finished the team final in an unprecedented 5th position, and for the second time qualified as a full team for the OG (FIG, 2019).

At the Beijing 2008 Olympic Games, Jade Barbosa and Ana Cláudia Silva qualified for the AA final and ranked 10th and 22nd respectively. Jade Barbosa also took part in the vault final, where she finished 7th. And Daiane dos Santos ended in 6th place in the floor exercise final. It is worth highlighting that Brazil competed for the first time in an Olympic team final, finishing in 8th place (FIG, 2019).

Table 3
Brazilian gymnasts in OG and WC from 2001 to 2008, and the states they represented.

EVENT	GYMNASTS REPRESENTING BRAZIL
2001 WC	Camila Comin (PR), Coral Borba (RJ), Daiane dos Santos (RS), Daniele Hypolito (RJ), Heine Araújo (RJ), Stefani Salani (SP)**
2002 WC *	Caroline Molinari (PR), Daiane dos Santos (RS) (did not compete), Daniele Hypolito (RJ)
2003 WC	Ana Paula Rodrigues (PR), Camila Comin (PR), Caroline Molinari (PR), Daiane dos Santos (RS), Daniele Hypolito (RJ), Laís Souza (PR)
2004 OG	Ana Paula Rodrigues (PR), Camila Comin (PR), Caroline Molinari (PR), Daiane dos Santos (RS), Daniele Hypolito (RJ), Laís Souza (PR)
2005 WC *	Daiane dos Santos (RS), Daniele Hypolito (RJ)
2006 WC	Bruna Costa (SP), Camila Comin (PR), Daiane dos Santos (RS), Daniele Hypolito (RJ), Juliana Santos (RS), Laís Souza (PR)
2007 WC	Ana Cláudia Silva (PR), Daiane dos Santos (RS), Daniele Hypolito (RJ), Jade Barbosa (RJ), Kiuani Dias (PR), Laís Souza (PR)
2008 OG	Ana Cláudia Silva (PR), Ethiene Franco (PR), Daiane dos Santos (SP), Daniele Hypolito (RJ), Jade Barbosa (RJ), Laís Souza (SP)

Source: Adapted from Schiavon (2009) and FIG (2019). *Apparatus events only (specialists). **Rio Grande do Sul (RS), Rio de Janeiro (RJ), São Paulo (SP) and Paraná (PR).

The end of 2008 also marked the conclusion of the centralized training system of the permanent national team and the departure of coaches Oleg and Nádia Ostapenko. According to Mrs. Alice Tanabe, chair of the Brazilian Gymnastics Federation WAG Technical Committee at the time, "the permanent team may be restored in the future. Whoever takes over the Brazilian Gymnastics Federation administration can present a new project. But there are people who are against it" (Pombo & Ohata, 2008). Among the reasons for opposing the centralized permanent team, we can mention the negative aspects of this system as perceived by AG coaches, such as rigorous training, monopolization of athletes, loss of talented gymnasts who did not adapt to join the system, devaluation of Brazilian coaches, among others. This suggests that the Soviet model was not adequately adapted to the reality of WAG in Brazil (Nunomura & Oliveira, 2012). In this sense, Bortoleto and Schiavon (2018, p. 92) point out that:

Nevertheless, criticisms of this model were later intensified, since many clubs that "ceded" their main gymnasts to the permanent team were unable to maintain the same level of performance, as those athletes who were their references ("mirrors") were no longer present in their gyms. Added to this dissatisfaction was the lack of a policy to "democratize" the knowledge of foreign specialists, i.e., to set up a continuous process to optimize the exchange between Brazilian and foreign coaches. It is also clear that the discontent due to the "devaluation" of Brazilian coaches aggravated the problem, culminating in the difficulty to renew club teams and, later, the national team.

Under the management of Mrs. Vicélia Florenzano, WAG undoubtedly experienced a period of growth and development in Brazil, characterized by the construction of its own headquarters, the structuring of a training center according to

international standards, the introduction of centralized training system of the national permanent team, the arrival of three foreign coaches to work with the team in Curitiba, and ultimately, more significant results in the main international competitions (Oliveira, 2007). Different studies confirm that the most significant changes occurred in this period, contributing to the major development of Brazilian WAG and better international results. Despite this, it was still possible to see problems in the administration and general infrastructure of this sport nationally (Nunomura & Oliveira, 2012; Schiavon et al., 2013; Costa, 2018).

This period was marked by an increase in public and private investment in sports in Brazil with the implementation of the Agnelo/Piva Act in 2001, the Sports Incentive Act in 2006, and the Athlete Grant Program in 2005, among others (Oliveira, 2010). If Brazilian WAG started this period with Daniele Hypólito receiving financial support from soccer player Ronaldo in 2001, the following years were impacted by the laws and programs mentioned above.

This sum of investments brought significant advances to a country with no previous tradition in the sport and which did not imagine featuring so quickly among the best in the world. Team Finals (CIV) and Individual Apparatus Finals (CIII) were reached and medals were won in World Championships by Daniele Hypolito (CIII), Daiane dos Santos (CIII) and Jade Barbosa (Individual All-Around/CII) (Schiavon & Paes, 2012, p. 768).

Regarding the Agnelo/Piva Act, Oliveira (2010, p. 158) points out that "The security afforded to the Brazilian Gymnastics Confederation by Agnelo/Piva Act resources enabled the organization to carry out long-term planning, an unconceivable condition in the period prior to the implementation of this act in 2001". Moreover, such resources made it possible to Brazilian Gymnastics Federation introduce several initiatives that contributed decisively to the technical improvement of WAG, such as hiring foreign coaches and a multidisciplinary team, obtaining imported equipment, opportunities for training abroad, participation in international competitions, maintenance of Curitiba training center, among others (Oliveira, 2010). In short, funds from the Agnelo/Piva Act were extremely important for the development of high-performance WAG in Brazil, and it was later complemented by the Sports Incentive Act (Oliveira, 2010).

The Athlete Grant Program, the first federal policy for directly subsidize athletes (Corrêa *et al.*, 2014), was introduced in 2005. By the end of 2009, it assisted 27 WAG gymnasts in all age group categories (student, national, international, Olympic athletes). It is important to mention that no gymnast benefiting from this grant took part in WC or OG until 2008 (Lima, 2016). This is due to the program criteria, which until 2012 did not allow athletes to have sponsorships and/or receive salaries (Oliveira & Bortoleto, 2012; Corrêa *et al.*, 2014). The national team gymnasts didn't benefit from this program because they received a salary from the Brazilian Gymnastics Federation and its official sponsor.

All these important advances in Brazilian WAG, especially the results at international competitions, impacted the history of this sport nationally. However, they did not have the same satisfactory impact at the national level. In fact, "[…] gymnasts, clubs and state federations did not follow this evolution, continuing to suffer from the typical problems of Brazilian amateur sport" (Oliveira, 2010,

p.175), as follows.

2009-2021 – Decentralization and establishment of training camps

The year 2009 marked significant changes in Brazilian gymnastics. Following the dissolution of the permanent national team in 2008, the WAG team entered a phase of adjustment to a new format introduced by the incoming administration of the Brazilian Gymnastics Federation. This new approach saw a departure from the centralization of gymnasts, who now convened for training only in the periods closer to competitions (Poffo, 2009).

With the conclusion of the 2005-2008 Olympic cycle and the subsequent Brazilian Gymnastics Federation elections in 2009, Mrs. Maria Luciene Cacho Resende from the state of Sergipe assumed the presidency. Consequently, after 18 years headquartered in Curitiba under the management of Mrs. Vicélia Florenzano from Paraná, the Brazilian Gymnastics Federation relocated its headquarters to Aracajú in Sergipe. This marked the first time the office was situated outside the South or Southeast regions of Brazil (Império, 2009).

The training center in Curitiba, which had been utilized by the Brazilian national team for years, was repurposed for gymnasts competing under the Paraná Gymnastics Federation (Império, 2009). On occasion, prior to international competitions, the Brazilian national team would convene there for training (Poffo, 2009).

In the first competition of the 2009-2012 Olympic cycle, characterized by an adaptation to the newly decentralized training system, four newcomer gymnasts represented Brazil at the 2009 WC in London, England. Bruna Leal achieved the highest ranking among Brazilians in this competition, securing 14th place in the AA (FIG, 2009).

In the following year, the 2010 WC in Rotterdam, the Brazilian team that had previously been Olympic finalists finished in 10th place. Notably, Jade Barbosa, returning to training after a prolonged absence due to a wrist injury, secured 3rd place on vault. This marked her second medal in WC, Brazil's first in this apparatus, and the fourth WC medal won by Brazilian WAG.

Despite the promising start to this cycle for Brazilian WAG, subsequent championships in the 2009-2012 cycle did not indicate sustained development from the centralized training system era. At the 2011 pre-Olympic WC in Tokyo, despite Daniele Hypólito qualifying 13th in the AA and Jade Barbosa placing 4th in the vault event, the Brazilian team finished in 14th place, failing to secure a full team qualification for the London 2012 Olympic Games (FIG, 2019).

Brazil's qualification came only through the test event in London in early 2012 (FIG, 2019), where the team clinched the last spot by finishing in 4th place. However, at the 2012 OG, the Brazilian WAG team underperformed, failing to advance beyond the qualifying round and ultimately finishing last among twelve teams (FIG, 2019).

The period between 2009 and 2012 was marked by injuries, challenges in renewing the team due to a limited number of athletes, and a political issue involving one of the top gymnasts. Notable instances include Adrian Gomes, who missed the 2012 OG due to a spinal injury sustained during training; Ana Cláudia Silva, who retired from the sport after suffering an elbow injury and missing the 2009 WC; Laís Souza, who broke her finger before the

2012 OG; and Jade Barbosa, who, as mentioned earlier, missed the 2012 OG due to a dispute with the Brazilian Gymnastics Federation, among other injuries and retirements.

Nunomura and Oliveira (2012) point out that issues related to the rigidity of training, overtraining, and the uneven development of WAG in different regions of Brazil were some of the criticisms that emerged during and after the 2005-2008 Olympic cycle regarding the centralized training system. According to the authors, some of these problems stemmed from the lack of adaptation of this system, which was imported from the Soviet Union, to the specific characteristics of AG in Brazil. Among these characteristics was the crucial role of clubs in the detection, selection, and development of athletes.

By inviting the best gymnasts into the permanent national team, the institutions have been weakened, as they lost their references for future generations. Coaches were forced to send their athletes to the centralized training system, as keeping them in their clubs, would result in stagnation compared to those training under the centralized system, which was supported by a multidisciplinary team and equipped with better facilities. […] With the loss of these athletes, clubs and coaches felt demotivated to pursue high-performance goals in the sport (Nunomura & Oliveira, 2012, p. 384).

When Brazil secured the right to host the 2016 Olympic Games, several measures were initiated to enhance AG participation. Without a specific training center for the national team since 2009, and amid changes in the Brazilian Gymnastics Federation's administration and office location, the Team Brazil AG Training Center (TC) was inaugurated in 2012. This initiative was a collaboration between the Brazilian Olympic Committee and the Brazilian Gymnastics Federation, utilizing the Barra da Tijuca velodrome in Rio de Janeiro, a legacy of the 2007 Pan American Games.

The AG gym was set up in the central area of the velodrome track and featured around 100 pieces of Spieth equipment, including a pit, tumble track, tumbling, and fitness and physiotherapy equipment (Ministério do Esporte, 2012). Besides AG, the TC was also used for cycling and speed skating. Consequently, the facility was not entirely suitable for AG, primarily due to the noise, but it was the best available option in Brazil at the time.

However, this project did not last more than a year; it was inaugurated in April 2012 and ended in February 2013 due to the demolition of the velodrome to make way for a new facility for the Rio 2016 Olympic Games. As a result, the national team gymnasts were once again left without a specific and adequate place to train that met international standards (Gismondi, 2013). As a temporary solution, the Brazilian Olympic Committee and Brazilian Gymnastics Federation relocated the WAG team to train in Três Rios, Rio de Janeiro, until a new TC could be constructed (Gismondi, 2013).

Another project developed with the 2016 Olympic Games in sight was the hiring of a new head coach. Since the departure of Ukrainian coach Oleg Ostapenko in 2008, the Brazilian WAG team had been without a head coach. In response, the Brazilian Olympic Committee hired Russian coach Alexander Alexandrov, facilitated by a partnership between the Brazilian Olympic Committee and the Brazilian Gymnastics Federation. This move aimed to improve the development of AG in Brazil and was made

possible through funds from the Agnelo/Piva Act (Ministério do Esporte, 2013).

In 2014, the Brazilian Gymnastics Federation (CBG), in partnership with the Brazilian Ministry of Sports (MS), purchased sets of FIG-approved equipment, which were distributed in 2015 to several Brazilian states (Ministério do Esporte, 2014; Lima, 2016). Specifically, seven states received WAG equipment: Aracaju (SE), Belém (PA), Brasília (DF), Curitiba (PR), Natal (RN), Porto Alegre (RS), and Rio de Janeiro (RJ) (Ministério do Esporte, 2014). According to the Ministry of Sports (2015), "The purchase is the largest import of AG equipment made by Brazil in the last 40 years […]."

This investment in AG equipment was the largest ever made in Brazil. The president of the Brazilian Gymnastics Federation, Mrs. Luciene Resende, stated that *"[…] it will contribute immensely to the further growth of Olympic sport. I am sure that the technical improvement will be extremely significant and that we will certainly achieve excellent results in the future […]*" (Ministério do Esporte, 2014). However, the criteria for distributing the equipment were not disclosed, leading to "speculation and criticism" (Bortoleto & Schiavon, 2018, p. 94).

Without an official training center for camps since 2013, following the demolition of the velodrome in Rio de Janeiro, the Brazilian Olympic Committee inaugurated the Team Brazil Training Center (TC) in Barra da Tijuca, Rio de Janeiro, in 2015. The former TC was relocated to the Artistic Gymnastics warm-up area of the gymnasium used for the 2016 Olympic Games and remains in use (Ministério do Esporte, 2015; COB, 2019). The facilities are fully equipped with temperature control, which is necessary given the location, and they have the support of medical and physiotherapy staff (COB, 2015).

In addition to modern sports and technology equipment, the COB will provide a cafeteria, study, medical and physiotherapy rooms, among others, for the Brazilian women's and men's national teams. […] The interventions carried out on site involved the construction of the pit and support rooms, and the purchase, import and installation of equipment (sports and technology). […] Measuring 2,500 square meters, the TC has separate rooms for women's and men's gymnastics, a meeting room, a room for consultation with the multidisciplinary teams, a medical room, an administration room, a common area for athletes, a cafeteria, a large physiotherapy room and a study room. The Artistic Gymnastics TC is the only one in Brazil with air conditioning. The facility will also have imagery analysis equipment, which is being imported from the United States, mainly for floor exercise and vault (COB, 2015).

The Rio de Janeiro National Training Center (TC) did not contribute as significantly as anticipated to the preparation for the 2016 Olympic Games, as athletes only gained access to the facility in 2015. Consequently, the national team utilized it for just about a year and a half. This facility has proven to be more beneficial as a legacy of the Olympic Games, serving the post-Rio 2016 generation more extensively.

Regarding the competitions of the 2013-2016 Olympic cycle, there were no noteworthy results except for the 2016 Olympic Games. At the 2013 World Championships in Antwerp, only two Brazilian gymnasts competed: Daniele Hypolito, who participated in two

apparatus, and Letícia Costa, who competed in the all-around (AA) and finished in 28th place (FIG, 2019). The best result for Brazil was Daniele Hypolito's 13th place on the balance beam.

In the 2014 World Championships in Nanning, China, Brazil finished in 16th place, with the best individual result being Daniele Hypolito's 34th place in the AA (FIG, 2019).

At the 2015 pre-Olympic World Championships in Glasgow, Scotland, the Brazilian team finished in 9th place, once again failing to qualify directly for the Olympic Games with a full team (FIG, 2019). Lorrane Oliveira achieved the 14th place in the AA and was the highest-ranked Brazilian woman at the competition. Flavia Saraiva also qualified for the AA final in 14th place but ended up in 24th place after several mistakes on the balance beam. Additionally, Jade Barbosa was returning from an injury, and Rebeca Andrade was unable to compete due to injury.

The qualification of a full Brazilian team to compete in the Rio 2016 Olympic Games was secured at the Olympic Test Event in 2016, where Brazil finished in first place, securing one of the four remaining spots (FIG, 2019). Rebeca Andrade's performance, particularly on two apparatus, was instrumental in helping the team secure this Olympic berth.

At the Olympic Games in Rio de Janeiro, Brazil achieved notable results. Highlights of the competition included Rebeca Andrade's 4th place in the all-around (AA) qualification and Flávia Saraiva's 3rd place on the balance beam. If Rebeca Andrade had maintained her qualifying score, she would have won the bronze medal, but after a few mistakes, she finished the AA competition in 11th place. In the balance beam final, Flávia Saraiva ended in 5th place. The Brazilian team qualified in 5th place for the finals, a position they were unable to sustain, ultimately finishing in 8th place (FIG, 2019).

The end of the 2013-2016 Olympic cycle marked significant changes for Brazilian Women's Artistic Gymnastics (WAG). Russian coach Alexander Alexandrov, who had been hired to improve the development of artistic gymnastics in Brazil, departed after his contract was not renewed. This period also saw the departure of several renowned Brazilian coaches. Keli Kitaura, who coached Rebeca Andrade, and Alexandre Carvalho, who coached Flávia Saraiva, moved to the USA in 2017. Ricardo Pereira, who coached Jade Barbosa and other prominent Brazilian gymnasts, relocated to Canada. In 2019, Roger Medina, Thaís Fidelis's coach, moved to Argentina to work with the national team. These departures represented a significant loss for Brazilian WAG, impacting its development and continuity.

In 2016, Brazilian coaches Alexandre Carvalho, Keli Kitaura, and Ricardo Pereira proposed a project to the Brazilian Olympic Committee (COB) to develop Women's Artistic Gymnastics (WAG) across different regions of Brazil, outside the traditionally dominant South and Southeast areas. The project aimed to disseminate and develop WAG and discover new talent. Despite several meetings, the COB rejected the project (Vecchioli, 2019). This rejection, among other factors, led to experienced and qualified Brazilian coaches leaving the country, highlighting the inadequate support for professionals involved in the sport in Brazil. This situation was exacerbated by the lack of response and engagement from the state federations responsible for organizing the

sport in Brazil, demonstrating a continued depreciation of Brazilian artistic gymnastics coaches.

In the 2017 World Championships (WC) held in Montreal, Canada, the only Brazilian gymnast to compete was Thaís Fidelis, who finished 4th in the floor exercise event. A significant development in 2018 was the COB's hiring of Valeri Liukin, a former Soviet Union athlete and WAG Olympic champion coach in the US, as a consultant for WAG. Liukin attended his first WC as a consultant in Doha that same year. However, his work with the national team began only in the second half of 2018, leaving insufficient time to prepare adequately for the 2019 pre-Olympic World Championship.

At the 2018 WC in Doha, Qatar, Brazil participated with a full team and finished 7th. Gymnasts Flávia Saraiva and Jade Barbosa qualified for the individual all-around finals, finishing 8th and 15th, respectively. Flávia Saraiva also qualified for the floor exercise final, where she finished in 5th place. These results underscored the ongoing challenges and potential within Brazilian WAG, despite the systemic issues and lack of adequate support for coaches and athletes.

The year 2019 proved to be a turning point for the worse for the sport in Brazil. After four consecutive Olympic Games (OG) with a full team, Brazil did not qualify for the team event in Tokyo 2020. By 2019, only gymnast Flávia Saraiva had secured a spot for the competition. Recurring injuries in Brazilian Women's Artistic Gymnastics (WAG) once again caused gymnasts to miss important competitions in this cycle (2017-2020), and the consequent lack of gymnasts competing at the international level hindered any chances of other qualifications for the OG.

Only six Brazilian athletes were able to attend the World Championships (WC) in Stuttgart, Germany, in 2019: Jade Barbosa, Flávia Saraiva, Rebeca Andrade, Lorrane Oliveira, Thaís Fidelis, and Carolyne Pedro. Unfortunately, the injuries of four of these gymnasts near and during the WC greatly undermined the team's performance and overall prospects.

The team's star, Rebeca Andrade, suffered that year her third anterior cruciate ligament in the right knee in four years. Lorrane Oliveira did not recover from an ankle injury and went to Germany to compete in only one apparatus event. To make matters worse, Carolyne Pedro was injured in the week of the competition, and Jade Barbosa sprained her knee in the first apparatus event of the Brazilian presentation, the vault, and was unable to continue in the competition (Vecchioli, 2019, *online*).

Other than the aforementioned athletes, few were able to compete for the WAG national team. This caused a great gap in the sport in Brazil, i.e., there was no renewal. This is not an exclusive problem of this last cycle, as we see in the quote below from Schiavon *et al.* (2013), Looking the previous decade.

> […] The closeness between the number of high-performance gymnasts in the senior category and the number of gymnasts needed to make up the Brazilian team is a significant issue. There are no reserve gymnasts of the same technical level, leaving coaches with limited options for assembling national teams. Consequently, there is insufficient renewal within the team, with the same gymnasts remaining on the Brazilian team across multiple Olympic cycles (Schiavon *et al.*, 2013, p. 433).

For the 2019 World Championships, gymnasts who no longer trained full-time and had not participated in international competitions for years, or who were still inexperienced in the senior category and/or below the technical level, were called up. This included Letícia Costa, who had not competed at a high level for about four years, and Isabel Barbosa, who was just starting in the senior category. The team finished 14th overall; the best results came from gymnast Flávia Saraiva, who placed 7th in the individual all-around, 6th on the balance beam, and 4th in the floor exercise, making her the only Brazilian to qualify for the Olympic Games at this World Championship. The second and final Olympic spot was secured by gymnast Rebeca Andrade at the Pan American Games in 2021 in Rio de Janeiro.

With the postponement of the 2020 Olympic Games to 2021 due to the COVID-19 outbreak, Brazil was represented only by individual gymnasts Flávia Saraiva and Rebeca Andrade. Unfortunately, another injury on the eve of the competition caused Flávia Saraiva to compete while injured; she managed to qualify for the balance beam final and finished 7th.

The Tokyo Olympics were a milestone for Brazilian WAG. Previously, Brazil had never won an Olympic medal in women's artistic gymnastics, but Rebeca Andrade changed that by winning silver in the individual all-around and gold in the vault event. Despite several gymnasts being injured, Rebeca Andrade was the only representative at the World Championships later that year. Although World Championships are typically not held in Olympic years, the postponement of the 2020 Olympics to 2021 resulted in both events occurring in the same year. Despite the strain of competing in the Olympics, Rebeca Andrade participated in only three apparatus events and achieved remarkable results, winning gold in the vault and silver in the uneven bars.

In a more specific analysis of the results obtained, focusing first on the performance of the Brazilian team as a whole, we observe (Figure 2) an improvement in the World Championships (WC) between 1995 and 2007. Regarding the Olympic Games (OG) in which Brazil participated with a full team, there was also an improvement in 2008 compared to the previous edition (Figure 3).

Table 4
Brazilian gymnasts in OG and WC from 2009 to 2021 and the states they represented.

EVENT	GYMNASTS
2009 WC	Bruna Leal (PR), Ethiene Franco (PR), Khiuani Dias (PR), Priscila Cobelo (PR)*
2010 WC	Adrian Gomes (RS), Bruna Leal (PR), Daniele Hypolito (RJ), Ethiene Franco, Jade Barbosa (RJ), Priscila Cobelo (PR)
2011 WC	Adrian Gomes (RS), Bruna Leal (PR), Daiane dos Santos (SP), Daniele Hypolito (RJ), Jade Barbosa (RJ), Priscila Cobelo (PR)
2012 OG	Bruna Leal (PR), Ethiene Franco (PR), Daiane dos Santos (SP), Daniele Hypolito (RJ), Harumy Freitas (PR)
2013 WC	Daniele Hypolito (PR), Letícia Costa (RJ)
2014 WC	Daniele Hypolito (PR), Isabelle Cruz (RJ), Julie Sinmon (RJ), Letícia Costa (RJ), Maria Cecília Cruz (RJ), Mariana Oliveira (PR)
2015 WC	Daniele Hypolito (PR), Flávia Saraiva (RJ), Jade Barbosa (RJ), Lorrane Oliveira (PR), Letícia Costa (RJ), Thauany Araújo (RJ)
2016 OG	Daniele Hypolito (PR), Flávia Saraiva (RJ), Jade Barbosa (RJ), Lorrane Oliveira (RJ), Rebeca Andrade (RJ)
2017 WC	Thaís Fidelis (PR)
2018 WC	Flávia Saraiva (RJ), Jade Barbosa (RJ), Lorrane Oliveira (RJ), Rebeca Andrade (RJ), Thaís Fidelis (PR)
2019 WC	Flávia Saraiva (RJ), Jade Barbosa (RJ), Letícia Costa (RJ), Lorrane Oliveira (RJ), Thaís Fidelis (PR)
2021 OG	Flávia Saraiva (RJ), Rebeca Andrade (RJ)
2021 WC	Rebeca Andrade (RJ)

Source: Adapted and updated from Lima (2020). * Rio Grande do Sul (RS), Rio de Janeiro (RJ), São Paulo (SP) and Paraná (PR).

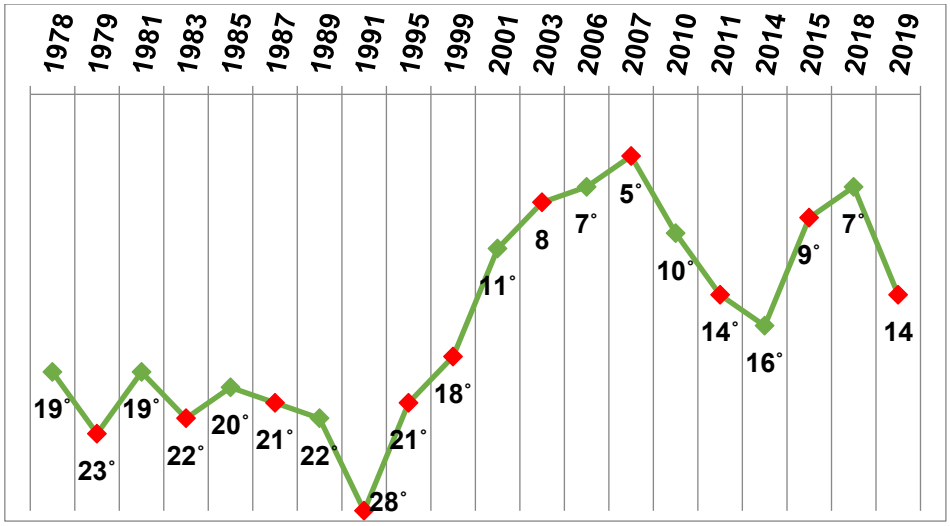

Figure 2. Brazilian WAG results in the team event in WC[1].
Key: Red squares indicate pre-Olympic WC.

[1] Brazil did not compete with a full team in the 2021 WC and the 2021 OG.

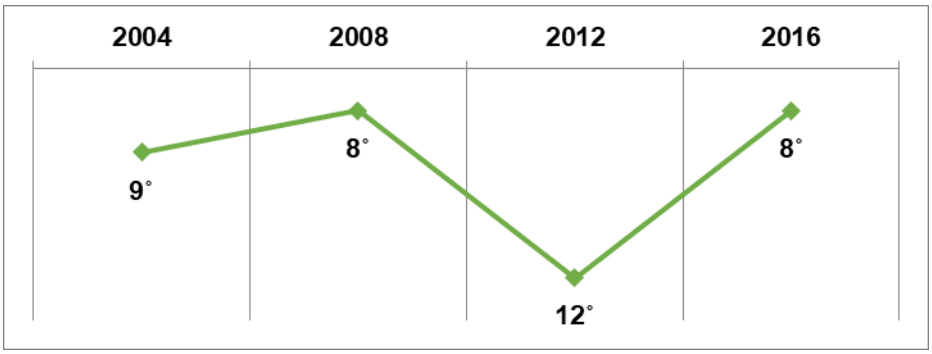

Figure 3. Brazilian WAG results at the OG Team event.

These improved results in the team event in both WC and OG can be linked to the "better" structure of the CBG with the establishment of its own headquarters in 1995 (the organization's first headquarters), the improved infrastructure available for training with the Curitiba TC, the formation of a permanent national team from 2001, the arrival of renowned foreign coaches, and the development of Brazilian coaches who were able to work closely with the Ukrainians. It is worth mentioning that such initiatives were only made possible and implemented with the increase in public and private investment in sports in Brazil during this period, especially with funding from the Agnelo/Piva Act.

However, a decrease in performance in the team event is observed in the period subsequent to 2008 until 2014, even though Brazil was chosen to host the Rio 2016 Olympic Games. This decline is observed in both WC and OG. The new non-centralized system, the end of the permanent national team and the departure of the Ukrainian coaches in 2008, the lack of a fixed TC for the national team until 2015, and the absence of a head coach from 2009 to 2013 possibly contributed to this situation. Additionally, the previously mentioned "aftereffects" of the negative aspects of the entire system implemented until 2008, which valued and focused on a national team with a specific profile, ended up not developing the sport in the rest of the country and excluding gymnasts who did not fit that profile.

Although performance starts improving again from 2014 in both tournaments, this is likely the result of investments and strategies aimed at the Rio 2016 Olympic Games. These strategies and initiatives for that competition began to effectively influence the sport's results, continuing to show a growing trend in the years following the 2016 Olympic Games. This trend does not happen after other Olympic Games (Figure 4), when there is typically a drop at the beginning of a new Olympic cycle.

Nonetheless, from 2019 onwards, it has been more challenging to maintain good results, despite Brazil achieving its best results ever in 2021. Several factors contribute to this difficulty, similar to the previous period of decline, including a large number of injuries and a lack of gymnasts capable of representing the country internationally. This situation persisted up to 2021, even with the recent Olympic medals, and was exacerbated by the pandemic, which brought many problems, especially for a large country like Brazil, which faced numerous political and social obstacles during that period. As previously mentioned, currently, Brazil has only six

gymnasts at the international level, which is not the case for the top countries in the sport, where there is a steady replacement of athletes. In Brazil, when injuries occur, there are not enough gymnasts of the same level to replace them. Although these six gymnasts currently receive all necessary support in funding and infrastructure, support is also needed for developing new gymnasts and investing in training new coaches and valuing these professionals. Otherwise, the problems with replacing gymnasts will persist, as coaches will continue to leave for other countries.

Attempting to explain this situation, Vecchioli (2019) points out that "of the 24 athletes who competed in the Brazilian U-16 and U-14 Championships in 2015, only one was in the Brazilian Championship this year: Carolyne Pedro, precisely the champion of that tournament and the only one to make it to the national team, as a reserve." The others ended up abandoning the sport due to lack of prospects and support.

Regarding the best results in the individual all-around event obtained by Brazilian women gymnasts in WC and OG, there is an unstable period of results from 1966 to 1985 and a decline from 1987 to 1992 (Figures 4 and 5). However, analyzing the chart as a whole, we observe significant improvement from 2001, when a process of striving for medals began, with Jade Barbosa obtaining the best result ever in 2007 in a pre-Olympic WC, considered the strongest of the Olympic cycles for being a qualifier for OG.

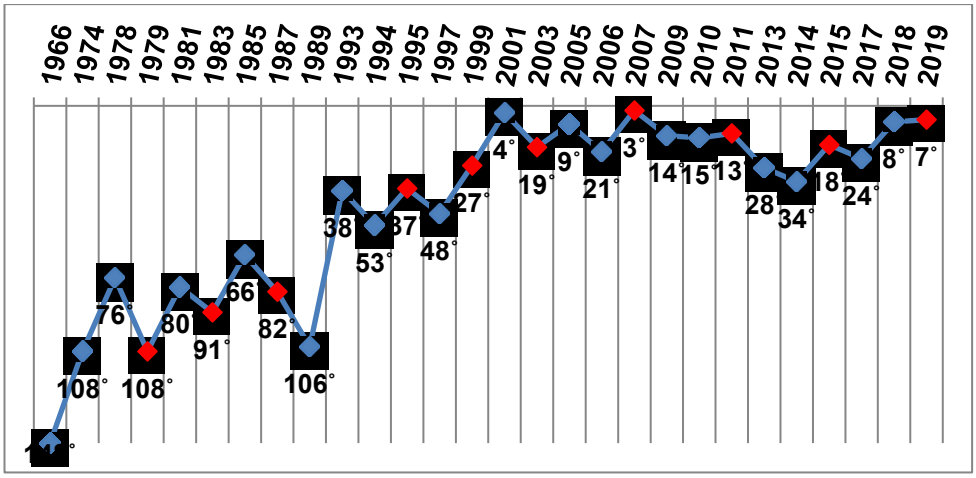

Figure 4. Best results by Brazilian gymnasts at WC in All Around event.[2]
Key: Red squares indicate pre-Olympic WC.

[2] In the 2021 WC, Brazil did not compete in the individual all-around event, only in three apparatus events (vault, uneven bars and balance beam). In 2020 there was no WC.

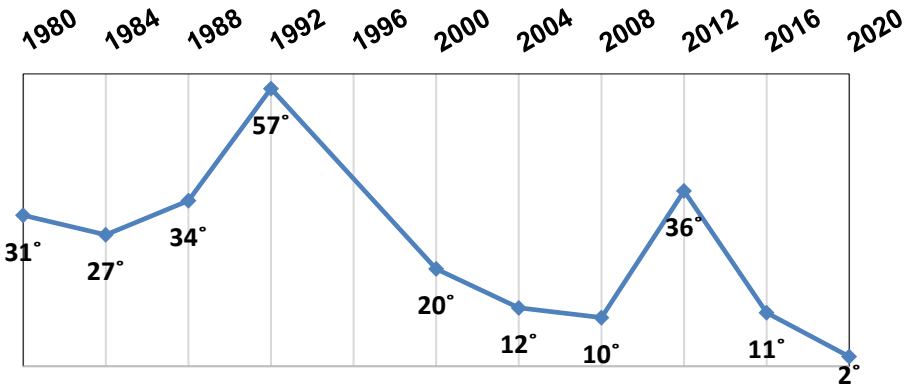

Figure 5. Best results by Brazilian WAG at Individual all-around event at OG.

These results can be attributed to a lack of support, financial difficulties, a reduced number of training sites, and inadequate infrastructure for high-performance artistic gymnastics (AG) in the 1980s and early 1990s, in addition to amateurism and a lack of structure, mainly within the CBG and the COB itself. The subsequent improvement in results starting in 1993 and the decline beginning in 2011 mirror the reasons mentioned above regarding the team event results, marking a trend in Brazilian WAG during this period as a whole. The results follow a growing trend, especially if we look at the main WC (pre-Olympics), and show that the gymnasts, despite facing all the difficulties within Brazilian WAG and competing against many countries with more robust structures and organization, have been achieving significant results for Brazil.

Lastly, it is worth stressing that the earliest participations of Brazilian women gymnasts in these international championships were key to the development and (re)structuring of Brazilian WAG. "It was a process in which the sport was gradually developed until the athletes were able to perform competently on the international stage and achieve a technical level that allowed them to compete against major world powers" (Costa, 2018, p. 30). The gymnasts from these early periods opened doors and helped Brazil achieve not only technical competence but also recognition and experience for the judges and for the International Gymnastics Federation.

Finally, it seems that the WAG in Brazil can improve in terms of governance, infrastructure, coach education and recognition, media support, local and state-level club support, transparency in management, among other aspects. There has certainly been an improvement in international competition results, but the local reality across the country does not follow the same trend.

CONCLUSION: PATH TO THE FUTURE

This overview of Brazilian WAG, based in the international competition achievements, clearly reveals major improvements of national team athletes. The trajectory of Brazilian gymnasts in Olympic Games and World Championships shows progressive results, culminating in the silver medal in the individual all-around event and the gold medal in the vault final, both won by Rebeca Andrade at the Tokyo 2020 OG, placing Brazil among the best countries in this sport today. For many years the achievements were based on personal initiatives, mainly by coaches, clubs and

gymnast's parents (Schiavon, 2009). Looking at the Olympic champion, Rebeca Andrade, a similar path can be observed in her carrier before joining the Brazilian national team.

Over these 55 years of Brazilian participation in WAG WC and OG, the last two phases/periods mark a drastic change in the national reality. Despite the positive image that the recent results bring about the development of this sport, there is still much to improve with respect to countries considered world leaders.

It is important to point out that the process of collecting and systematizing the data that guide this study was not an easy task due to the lack of official archiving of the state federations and CBG. Understand the historical development process is crucial to grasp the gaps and issues remaining. It is possible to say, for example, that all the gymnasts representing Brazil in WC and OG come from and were trained in the Brazilian South and Southeast regions, with the exception of Ana Claudia Silva, who started in the Northeast region (Natal-Rio Grande do Norte) and moves south to develop while still in the begging of her sport carrier.

The hiring of foreign coaches certainly contributed to the international successes of Brazilian WAG, but their experience was not spread and shared accordingly in the national community. Some Brazilian coaches had the chance to work alongside those renowned foreign coaches or had their gymnasts co-coached by them for some time. It seems that the contracts signed with these world-class coaches did not allow for a systematic and intentional training of new generations of Brazilian coaches. Considering that "the hiring was part of the planning of the COB and the CBG to improve the development of the sport in Brazil" (Ministério do Esporte, 2013), it seems we have not totally achieved this goal yet.

In order to develop the sport in the country, further long-term programs need to be implemented (Bortoleto & Schiavon, 2018; Lima, 2020), ensuring support for clubs that operate in the youth categories and developing programs that guarantee support for clubs and coaches that form the new generations of gymnasts. Some reforms in public policies and a broad training program for managers of state federations could help in this process. Finally, the recognition of Brazilian coaches on the same level as foreigners is urgent and necessary.

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ARMENIAN ADULT MALE ARTISTIC GYMNASTS SPORT CAREER TERMINATION REASONS

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Abstract

The information about the reasons for sports career (SC) termination among athletes is of significant importance, as it provides a theoretical foundation to prevent early withdrawal. A sociological survey was conducted among 76 former male artistic gymnasts who have ended their careers to determine the causes of SC termination. As a result, 11 different reasons for SC termination were identified. The most frequent reasons include sports injuries (35.52%), mandatory military service (31.57%), and employment (25.0%). The least mentioned reasons are coach-related issues (5.26%), health problems (2.63%), and age (2.63%). The survey offers a broader understanding of why Armenian athletes terminate their sports careers. This insight will enable the governing bodies of Armenian gymnastics and sports to provide targeted assistance to adult artistic gymnasts, helping to prevent early withdrawal in the future.

Keywords: *sports career, termination, reasons, artistic gymnast.*

INTRODUCTION

Each person's career is an indicator of their success in life since every individual reaches a certain status through professional development (Rykova & Pokatov, 2020). In trying to achieve success in any sphere of human activity, including sports, one faces numerous challenges and hardships that can hamper desired progress or cause its termination altogether. A sports career involves years of sports activity characterized by regular and constant self-development in one or several sports, aimed at high achievements (Stambulova, 1997). Numerous studies have been conducted among female and male athletes in various countries in recent decades to uncover the actual reasons for terminating their sports careers (Lavallee et al., 1997; Kerr & Dacyshyn, 2000; Stambulova et al., 2007; Moesch et al., 2012; Carapinheira et al., 2018, etc.). Interestingly, current research reveals certain differences among studies conducted in different countries. For instance, according to Moesch et al. (2012), the lack of motivation and injuries top the list of reasons for sports withdrawal among Danish athletes. The study results of Dergach & Ryabinina (2011) demonstrate that 18–21-year-old Russian athletes withdraw from sports mainly because of a lack of motivation and financial instability, whereas the leading reasons for sports withdrawal among 22–25-year-old athletes are financial instability and non-sport-

related professional issues.These differences may be explained by the social and economic characteristics of the respective countries, as well as the level of popularity of certain sports or other factors. As is known, a low level of popularity of a certain sport in a given city or country can cause withdrawal (Dergach & Zavyalova, 2013; Swan et al., 2022).

Moreover, the athletes involved in a series of studies (Dergach & Ryabinina, 2011; Moesch et al., 2012; Dergach & Zavyalova, 2013) represent both team and individual sports. Therefore, the results tend to be relatively general and do not provide accurate information about the specific reasons for the termination of the sports careers (SC) of athletes in certain sports, including artistic gymnasts. Research by López de Subijana et al. (2020) reveals significant differences in sports careers between individual and team sports. Theoretically, this fact can impact the reasons for SC termination.

Thus, the analysis of sports literature suggests that there may be differences in the reasons limiting the SC of Armenian adult artistic gymnasts as well. The current research aims to reveal the reasons for the termination of the SC of Armenian adult male artistic gymnasts, as well as the age range of career termination.

METHODS

The survey was conducted with 76 former gymnasts. The participants were selected based on three criteria: they had to have started their training from the preliminary preparation stage, retired from sports at the age of 18 or later, and ended their sports careers (SC) in the past 10 years. In Armenia, the first stage of multi-year training is called preliminary preparation. From then on, children embark on their first training sessions. Typically, this stage starts at the age of 6 to 7, or sometimes even earlier (Khizantsyan & Seloumyan, 2016, p. 45).

Information and contact data about the participants were obtained from the Gymnastics Federation of Armenia. The survey was conducted in various gymnastics schools in Armenia (among coaches), the Armenian State Institute of Physical Culture and Sport (among students), as well as among former gymnasts currently engaged in activities other than sports. Former artistic gymnasts presently study and work in the institutions mentioned above. The questionnaire was individually presented to each participant in the study. The present research adopts a cross-sectional, retrospective design.

The sociological survey was carried out using a carefully developed questionnaire, which helped reveal the biographical data of the participants, the age at which they started and finished training, and the overall duration of their sports careers. An open-ended question was asked to find out the reasons for SC termination. In the open-ended question, the former athletes had to list the reason(s) for ending their sports careers. A qualitative content analysis of the reasons mentioned by the athletes was conducted. The reasons were carefully read and re-read, and subsequently grouped into categories with similar content. The statistical data were analyzed using the SPSS program with methodological standards of sports metrology (Zaciorski, 1982).

RESULTS

The study of the biographical data of the survey participants revealed that all of them had been champions and winners of various competitions among Armenian young and adult gymnasts. Additionally, 13.2% of them had won medals in various international gymnastics competitions. According to the biographical data of the survey subjects, at the time of ending their sports careers (SC), 7.89% were masters of sports of international class, 18.42% were masters of sports, 38.15% were candidates for master of sports, and 35.52% were gymnasts of the first adult category (first-class athletes). This classification of gymnast status is defined and awarded by the RA Ministry of Education, Science, Culture and Sports, and the Gymnastics Federation of Armenia (RA Government decision No. 587 of May 4, 2006).

Eleven reasons for the sports career (SC) termination of Armenian gymnasts have been identified. The leading reasons mentioned by athletes are sports injuries (35.52%), mandatory military service (31.57%), and employment (25.0%). These are followed by financial reasons (inadequate financial assistance or lack of it) (18.42%), lack of success (17.10%), lack of motivation (15.78%), family-related reasons (14.47%), and improper state of infrastructure and sports equipment (10.52%). The least mentioned reasons are coach-related issues (5.26%), health problems (2.63%), and age (2.63%) (Table 1).

Table 1
Armenian adult artistic gymnasts SC termination reasons (N=76)

N	**Reasons**	**n**	**%**
1	Sports injuries	27	35.52
2	Mandatory military service	24	31.57
3	Employment	19	25.0
4	Inadequate financial assistance or lack of it	14	18.42
5	Lack of success	13	17.10
6	Lack of motivation	12	15.78
7	Family-related reasons	11	14.47
8	Improper state of infrastructures and sports equipment	8	10.52
9	Coach-related reasons	4	5.26
10	Health problems	2	2.63
11	Age	2	2.63

The investigation of the age index of the athletes (the arithmetic means, standard deviations) revealed the following indicators: starting age of training 6.51 ± 1.41, training termination age 21.06 ± 3.28, and SC duration 14.55 ± 2.97. According to the Kolmogorov-Smirnov Test of Normality, the statistical data for SC duration (sample) do not match the law of normal distribution ($p < 0.05$). The same applies to the age indicators of sports termination ($p < 0.05$). Of the survey participants, 88.16% finished their SC between the ages of 18 and 24, and 11.84% finished between the ages of 25 and 31

DISCUSSION

It's no secret that athletes often sustain various injuries during training and competitions (Lebedikhina, 2017; Thomas & Thomas, 2019). Sports injuries occur during athletic activities or exercise and can result from accidents, poor training techniques, inadequate equipment, or overuse of a particular body part (Elmagd, 2016). It's worth noting that artistic gymnastics is not considered one of the most injury-prone sports. Compared to others, its injury rate is considered average (Lebedikhina, 2017, p. 54). However, sports injuries remain a leading cause of sports career (SC) termination not only in artistic gymnastics but also in other sports (Ristolainen et al., 2012; Dergach & Zavyalova, 2013).

Studying cases across 16 different sports, Moesch et al. (2012) revealed that sports injuries are the main reason for SC termination among elite athletes. Enoksen (2011) concluded that injuries are the major reason for young Norwegian track and field athletes to leave the sport. Although sports injuries are considered an inherent risk of sports participation, experts have developed special methods to significantly reduce the likelihood of injuries if applied correctly (Aghajanyan, 2015). Currently, many coach activities contain methodological mistakes that contribute to sports injuries. It's estimated that 30-60% of injuries are caused by improper training methods and mistakes (Aghajanyan, 2015, pp. 435-437). Therefore, the role of the coach in preventing potential injuries cannot be overstated, along with the importance of sports doctors and rehabilitators. Rehabilitation after a sports injury is crucial for ensuring full recovery, minimizing time off from sports, and preventing reinjury (Dhillon et al., 2017).

Another major reason for sports career (SC) termination is mandatory military service. Armenian legislation mandates that all male citizens aged 18 must enlist for a 24-month military service (RA Law on Military Service and the Status of the Serviceman, Law No. HO-195-N of 15 November 2017). Withdrawal from training during this period significantly disrupts the principle of training continuity, considered one of the fundamental principles in sports preparation (Platonov, 2004, pp. 291-292). It's well known that breaks in training lead to de-adaptation processes in the body (Platonov, 2004, p. 145). Consequently, an athlete's sports results achieved after years of dedicated training can be dramatically affected due to insufficient training (Platonov, 2004, p. 148). Artistic gymnasts often struggle to regain their previous physical fitness due to lack of exercise, leading them to drop out of the sport. Responses from survey participants confirm this notion, with statements like "I was out of shape" and "I struggled to regain my previous physical fitness, but couldn't" being common. Others noted a lack of motivation to exercise after completing their military service. Therefore, it's evident that military service affects athletes' performance both physically and psychologically.

The third most mentioned reason for sports career (SC) termination is starting work (employment). On one hand, work provides an opportunity to earn money and begin a career. The need to earn money can become a decisive factor when athletes face financial problems. A study conducted by Dergach & Ryabinina (2011) reveals that 18.4% of athletes aged 22-25 give up sports due to financial instability. It's known that work can be balanced with training, and employment shouldn't always be seen as a reason to leave sports. However, unlike

individual sports, athletes in team sports often manage to combine training and work more effectively. According to a study by López de Subijana et al. (2020), team sports athletes typically reach their peak performance later than individual athletes, enjoy longer athletic careers, and more frequently balance their sport with work compared to athletes in individual sports.

The lack of financial assistance can lead athletes to give up sports, not only for artistic gymnasts but also for athletes engaged in other sports (Dergach & Zavyalova, 2013). The need for financial support or the opportunity to earn money through sports becomes more evident during adulthood. While the primary motivation for engaging in sports among athletes aged 16-18 is often emotional — such as socializing and traveling to various countries — after the age of 18, motives change significantly. At this stage, the primary motives for participating in sports are aspirations for sporting achievements and financial gain (Dergach & Zavyalova, 2013).

According to resolutions of the Government of the Republic of Armenia, only the top 10 athletes in the country receive financial awards each year (RA Government Resolution No. 187, February 20, 2020). Additionally, athletes who achieve significant success at international tournaments may receive financial support under certain government decisions (RA Government decision, December 15, 2022). Consequently, gymnasts who are talented and dedicated but have not yet achieved high-level results do not receive monetary or other support. In case of injuries or other training-related problems, gymnasts often have to overcome difficulties on their own.

Another reason for the sports career (SC) termination of artistic gymnasts is the lack of success. After years of training, athletes may feel unable to further develop their sports achievements or improve their abilities and skills. Consequently, their sports results may plateau or even regress, which can demotivate them from continuing their training. Sports achievements are influenced by various factors, which can be classified into three groups: individual factors (first group), scientific-technical progress (second group), and social-economic factors (third group) (Kholodov & Kuznetsov, 2003, pp. 327-333).

The factors in the first group pertain to the personal traits of the athlete, including innate gifts, abilities, and level of preparation. Factors in the second group are influenced by the effectiveness of the sports preparation system, encompassing modern training methods, a rational system of training, and technical, scientific, medical, and biological factors contributing to athlete preparation. The third group reflects the state of the sport in the country, the quality of specialists involved, and the general social and economic conditions affecting sports (Kholodov & Kuznetsov, 2003, p. 328).

While each of these factors is important, the gifts and talent of the athlete play a crucial role in their sports achievements. Sports genetics specialists assert that, similar to other human endeavors, an athlete's success is predominantly influenced by their genotype, accounting for 75-80% of their success, with other factors such as upbringing, teaching, training, and environment contributing 15-20% (Mosse, 2012).

Research conducted among former Russian athletes aged 17-23 reveals that the lack of success (the cessation or decline in performance growth) is the second main reason (31.25%) for quitting sports (Ivanova, 2019).

Some artistic gymnasts terminate their sports careers due to a lack of motivation, a reason acknowledged in numerous studies. For example, Moesch et al. (2012) found that responses indicating a lack of motivation as the main reason for withdrawing from sports totaled 26.5%, while Dergach & Zavyalova (2013) reported a figure of 12.5%. The lack of sports motivation may stem from inadequate motivation formation during sports preparation, which is considered one aspect of athletes' psychological preparation (Platonov, 2004). The coach's skills and knowledge play a crucial role in this regard.

Sports motivation is influenced by internal and external factors that change at different stages of an athlete's career (Ilin, 2002, p. 288). Babushkin (2014) suggests that inadequate recovery of stamina after training or competitions is one reason for the decline in sports motivation among elite athletes. This not only negatively affects athletes' psychological and emotional states but also their planned sports achievements and overall desire to engage in sports. To boost sports motivation, psycho-regulative training and rehabilitation massage are recommended (Babushkin, 2014).

Sports motivation has been extensively researched (Cratty, 1978; Munkácsi et al., 2012; Nunomura et al., 2012; Ilin, 2002; Babushkin, 2014), providing a better understanding of athletes' motivation-related issues.

Responses such as family issues, negative family attitudes toward their training, marriage, or moving to another country are categorized as family-related reasons, as recorded in the research by Moesch et al. (2012) and Dergach & Zavyalova (2013). Interestingly, female athletes tend to give up sports due to family-related issues more frequently than male athletes (Moesch et al., 2012).

Responses indicating "inadequate equipment in training halls," "inadequate and outdated equipment," or "insufficient levels of rehabilitation and hygiene resources" are considered reasons connected with the inadequate state of infrastructure and equipment. It's known that outdated or insufficient sports equipment negatively affects training quality, while high-quality equipment contributes positively to training efficiency (Kholodov & Kuznetsov, 2003, p. 330). Additionally, the role of infrastructure and sports equipment in injury prevention cannot be overstated (Aghajanyan, 2015, pp. 435-437).

Changes in coaches, their withdrawal from sports, or their relocation to another country, as well as deteriorating relations with athletes, can be factors limiting or terminating athletes' sports careers. However, based on the data, coach-related reasons are not primary factors for sports career (SC) termination among adult gymnasts. Generally, adult and elite athletes rarely end their sports careers due to coach-related issues, as indicated by various studies (Dergach & Zavyalova, 2013; Ivanova, 2019).

Two participants in the survey cited health problems as their main reasons for giving up sports. Since the specific types of health issues were not provided, no further analysis was conducted in this regard. Other authors often group health problems and injuries into a single category (Moesch et al., 2012; Ivanova, 2019). However, in the current research, they are not grouped together since health problems may not necessarily be related to sports, whereas sports injuries are typical of sports participation.

Age was one of the least-mentioned reasons, with only two participants (aged 28 and 31) noting it as a reason for terminating

their SC. Retirement from sports at this age can be considered somewhat standard, as there is a certain decline in sports indicators for artistic gymnasts starting around age 25 (Platonov, 2004, p. 448). Foreign experts rarely cite age as a reason for sports withdrawal in their research (Moesch et al., 2012; Dergach & Zavyalova, 2013). It's worth noting that athletes often struggle to maintain peak performance for an extended period due to the specific demands of their sports. Artistic gymnastics and combat sports, for example, typically require athletes to maintain a high level of adaptation for only 1-3 years, making it challenging to sustain top performance over a longer period. Top level performance in these sports over the period of 5-8 years is viewed as successful (Platonov, 2004, p. 444).

The current research does not mention several reasons for sports career (SC) termination that are commonly encountered in studies conducted in other countries among athletes of various sports, such as overtraining, physical and psychological fatigue, low popularity of the given sports, deselection, study reasons, and positive doping tests (Moesch et al., 2012; Dergach & Zavyalova, 2013; Ivanova, 2019; Savchenko, 2019).

Overtraining and physical and psychological fatigue are noteworthy, as they have been frequently mentioned in several studies (Dergach & Zavyalova, 2013; Ivanova, 2019; Savchenko, 2019). For instance, Savchenko (2019) identified overtraining as the primary reason for young athletes in martial arts (aged 16-18) to leave sports. In Ivanova's (2019) research, 41.25% of students aged 17-23 dropped out of sports due to physical and psychological fatigue. It's estimated that 7-20% of elite athletes experience overtraining (Platonov, 2015), with sports injuries and depression being related expressions of overtraining (Platonov, 2015). Overtrained athletes often exhibit weakness, mood decline, and a negative attitude toward training (Aghajanyan, 2015, p. 411).

While some reasons identified in this research (such as sports injuries and lack of motivation) theoretically may be connected with overtraining, further well-founded arguments are necessary to confirm or refute this hypothesis.

It's important to note that several factors limiting the sports careers of adult Armenian gymnasts may stem from the socio-economic characteristics of Armenia. Inadequate sports infrastructure conditions, insufficient financial support, and a lack of assistance for injury treatment or rehabilitation could be attributed to the socio-economic context of the country and the policies pursued in the sports sector. The sphere of sports in Armenia is overseen by the Ministry of Education, Science, Culture, and Sports of the Republic of Armenia (RA MoESCS) (Internet: www.escs.am/en). The activities of the sports sector and individual sports are regulated and developed by the RA MoESCS, the Olympic Committee, and federations in accordance with the legislation of the Republic of Armenia. An examination of the expenditures of the Armenian Gymnastics Federation in recent years has shown that finances have been primarily allocated for hosting championships and facilitating athlete participation in international events (Internet: www.escs.am). However, specific financial resources have not been earmarked in advance to provide assistance or support to individual athletes (such as injury recovery or financial aid).

The termination of a sports career should not always be viewed negatively,

although many athletes experience a range of psychological problems and difficulties during and after this transition (Ivanov & Stanislavskaya, 2009; Ivanova, 2019). Ending a sports career presents an opportunity for athletes to embark on a new career path. Statistics suggest that approximately 70% of athletes find employment in the sports field as coaches, heads of sports schools, lecturers at higher educational institutions, and so forth (Tsizidova, 2018, pp. 5-6).

The majority of participants in the research (88.16%) ended their sports careers between the ages of 18 and 24, highlighting the relevance of the identified reasons, especially during this period. The multi-year training period for male artistic gymnasts typically spans three stages: 1) preparation for high achievements (from 17 to 19); 2) maximizing individual potential (from 20 to 22); and 3) maintaining a high level of professionalism (from 23 to 24) (Platonov, 2004, p. 448).

It can be inferred that many Armenian gymnasts do not complete all stages of multi-year training. While the decision to continue or withdraw from sports is ultimately the athlete's personal right, from a sports perspective, a sports career can be considered complete when the athlete progresses through all stages of multi-year training.

LIMITATIONS

It's important to note that the reasons for terminating the sports careers of artistic gymnasts and athletes, in general, can be classified as voluntary or involuntary (Lavallee et al., 1997). However, the current research does not investigate this aspect. Additionally, some studies suggest variations in the reasons for sports career termination among adult athletes of different ages (Dergach & Ryabinina, 2011). Therefore, exploring the reasons for sports career termination among adult artistic gymnasts based on data from different age groups could provide valuable insights.

CONCLUSIONS

Among adult Armenian artistic gymnasts, 11 reasons for sports career (SC) termination have been identified, with three factors (sports injuries, mandatory military service, employment) emerging as more frequent determinants for withdrawing from sports. Both similarities and differences exist between the SC termination reasons of Armenian artistic gymnasts and those of foreign athletes. Notably, mandatory military service ranks among the leading reasons for Armenian artistic gymnasts, whereas it is absent in studies conducted by several foreign researchers. The findings of this study will empower the governing bodies of artistic gymnastics and sports in Armenia to offer more targeted assistance to adult artistic gymnasts, thereby preventing their premature departure from sports. It is advisable for the RA Government and the Gymnastics Federation of Armenia to extend support to gymnasts who have undergone systematic training for many years but have yet to achieve significant sporting success. Additionally, creating specialized training conditions for athletes enlisted in the army can help them maintain physical fitness and facilitate their return to sports later on. Thus, these measures will lay a positive foundation for extending the sports careers of athletes.

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MAXIMAL FORCES FOR PEAK HEIGHT AND FLIGHT DISTANCE ON VAULT IN MENS ARTISTIC GYMNASTICS?

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In memory to PD Dr. Klaus Knoll 1941 – 2022
From your gymnastics family.

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Abstract
Analysing the take-off forces on the vaulting table can help to inform the athlete about the vaulting technique. A measuring device was used to measure the forces during the Artistic World Championships 2019. The greatest forces were measured during Forward handspring. The mean maximum values were 5.4 times body weight (BW). The highest peak height was calculated for Forward handspring (tucked) at 2.9 m. The longest flight distance was 3.62 m for forward handspring and 3.59 m for tsukahara/kasamatsu. The statistical correlations between the forces and the peak height and flight distance could only be verified for Forward handspring. For the Tsukahara/Kasamatsu and the Yurchenko vaults, no correlation could be proven.

Keywords: *men's artistic gymnastics, vault, reaction forces.*

INTRODUCTION

The vault exercise is one of the shortest events in Artistic Gymnastics. It involves a 25-meter run-up, jumping on and off the springboard, an explosive take-off from the vaulting table, and a second flight phase with somersaults and twists. Successful execution of the vault is characterized by turns and twists around the body axes, achieving height in the second phase of flight, and a "stuck" landing, as judged by officials.

According to the rules of the International Gymnastics Federation, there must be an evident rise of the gymnast in the second flight phase compared to the take-off from the vaulting table (Fédération Internationale de Gymnastique, 2022).

Numerous research groups have dedicated their efforts to studying this apparatus. Their focus has consistently been on clarifying and explaining the sports technique and its correlation with movement parameters (Prassas et al., 2006). With this knowledge, athletes should aim to execute their technique almost perfectly to receive the highest scores from the judges.

To execute difficult vaults successfully, beginning the vault with the highest possible energy input, manifested as a high run-up

velocity, is essential. Several studies indicate that specific run-up velocities are also necessary for ensuring safe landings for various vaults (Fujihara et al., 2017; Naundorf et al., 2008; Schaerer et al., 2019). The optimal conversion of run-up velocity into vertical and horizontal take-off velocity, along with angular momentum on the vaulting board, has been less explored due to the complex measuring methods associated with the elastic spring system of the board (Čuk et al., 2011). Attempting to delve deeper into this phase, Sano et al. (2007), Lehmann (2018), and Lehmann et al. (2017) modeled take-off forces.

Research on the take-off from the vaulting table has focused on specific vaults or types using kinematic methods. Gutewort et al. (1973) and Leirich (1981) demonstrated that specific body positions can yield corresponding take-off parameters. Studies on the vaulting table for hand-spring forward and double somersault were undertaken by Irwin and Kerwin (2009). Hiley et al. (2015) assessed a planar seven-segment torque-driven computer simulation model of the contact phase in vaulting, specifically for a handspring double somersault vault performed by an elite gymnast. Optimized for both the vault and the athletes, the support phase on the table aims to generate an impulse allowing up to 2.5 rotations about the longitudinal axis and 3.5 rotations about the sagittal axis (Jemni & Sands, 2011).

Ultimately, the athlete's challenge lies in utilizing the energy from the table contact to achieve the required flight time and angular momentum for executing somersaults and twists.

From a mechanical perspective, it can be stated that the vertical take-off velocity (vz) determines the displacement in height of the center of mass (h_{disp_com}) from take-off to the peak height of the center of mass (h_{peak_com}) relative to the ground.

$$h_{disp\_com} = \frac{v_z^2}{2g} \quad (1)$$

The take-off velocity (v_z) can be calculated from the integral of the vertical force (F_z) over time.

$$v_z = \frac{1}{m}\int_{t1}^{t2} \dot{F}_z dt + v_{z0} \quad (2)$$

$$\dot{F}_z = F_z - m \cdot g \quad (3)$$

“A higher vertical take-off force on the table results in a greater peak BCG height during the second flight, and a higher BCG height after completing both the first and second saltos on the table.” (Čuk & Ferkolj, 2008).

It's essential to note that the interaction between the forces on the table and the corresponding position of the body’s center of mass (CoM) significantly influences the generation of optimal angular momentum for the second flight phase. The take-off from the vaulting table always involves an optimization between h_{disp_com} and angular momentum. The angular momentum about the lateral axis is consistently reduced during take-off. Additionally, the reduction in angular momentum is less for a handspring forward with stretched somersaults due to the higher angular momentum required for the stretched somersault (greater mass moment of inertia). Conversely, in a handspring forward followed by a tucked somersault, there is a more significant reduction in angular momentum (Knoll, 2002).

It's evident that the take-off from the vaulting table and the reaction forces are crucial. Published studies only cover take-off forces on the vaulting table. Küttner and Knoll (1988) measured forces on the vaulting horse, while during the 2001 World Championships, Schweizer (2003) used the

dynamometric method to investigate forces on the vaulting table, detecting maximum forces of up to 4700 N for the vaults.

Penitente et al. (2011) attempted to measure take-off forces using two portable force plates placed atop the vaulting table. National US Junior Olympic gymnasts participated in this study. Their chosen measurement setup meant the specific elastic properties of the vaulting table did not influence the vault. The study focused on the forces for each hand, recording forces of 1.4 times the body weight (BW; where BW = body mass · g) and vertical force impulses of up to 58 Ns (Penitente et al., 2011).

Knoll and his team employed this measurement method at various events, including the World Cups 2002, German World Championship Qualification 2007, and the German Championships 2008. They recorded forces up to 5 times BW for handspring forward vaults and 2 times BW for Kasamatsu/Tsukahara vaults (Knoll et al., 2014).

The aim of the present study was to determine whether a significant relationship exists between the reaction forces and the peak height of the center of mass (hpeak_com), as well as flight distance, on the vault in gymnastics.

METHODS

During the Artistic Gymnastics World Championships 2019, a force-measuring unit was integrated into the vaulting table, and synchronized 3D videometry was used to record reaction forces and flight parameters. In total, 308 men's vaults were recorded across all four competitions (qualification, all-around final, team final, and apparatus final) at the World Championships. To compare the forces across athletes, they were normalized to their respective body weight (BW). Athletes' body weight was determined using a force system installed on the still rings (Merz et al., 2023).

The force measuring unit utilized a specially developed force plate for the SPIETH vaulting table, equipped with four 3-dimensional (3D) force sensors based on strain gauges, operating at a 500 Hz sample rate. The specifications of the force measuring device and its calibration are detailed in Knoll et al. (2014).

The 3D videometry setup comprised two synchronized full HD cameras (Basler acA 1920–155 uc, USB 3.0, Basler AG, Ahrensburg, Germany; 100 fps; 1920x1200 px), positioned orthogonally in the spectator area. Camera one was situated behind the vault run-up, while camera two was positioned beside the vaulting table. The system's calibration for horizontal and vertical movement directions was achieved by digitizing a 4m measuring stick in both directions.

The dynamometric parameters analyzed included maximum resultant forces ($Fres_{max}$), maximum vertical forces (Fzmax), maximum horizontal forces (Fxmax), vertical force impulse (pz), as well as kinematic parameters h_{peak_com} and flight distance. These parameters were calculated using specialized software designed for this measurement system (Fig. 1).

Fx_{max} and Fz_{max} are the maximum forces from the captured force-time curves, and p_z is the integral of F_z minus body mass force (m·g) in the limits of the zero-crossing (Fig. 2).

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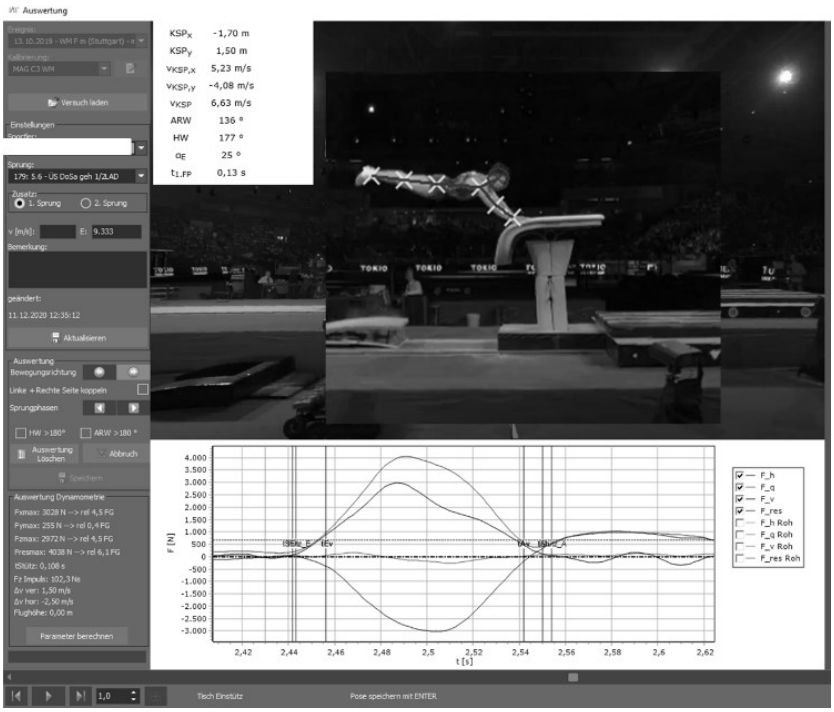

Fig. 1 Analysis software for the measurement system for vaulting table (MIS VT, measurement and information system vault)

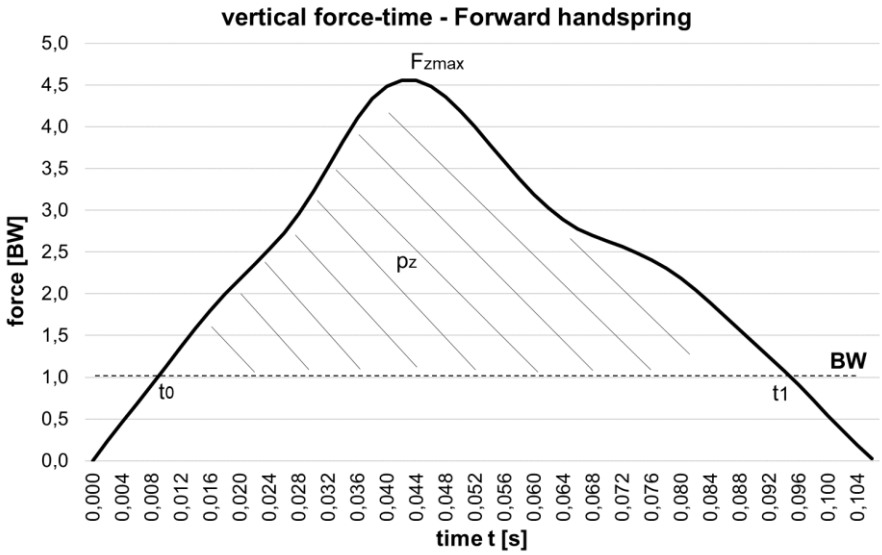

Fig. 2 Example of a vertical force-time curve for a Handspring forward with the evaluated parameters

The h_{peak_com} was determined using the flight parabola (Fig. 3). To establish this, positions at take-off from the table and landing were utilized to determine the trajectory of the CoM. The CoM was determined using a 7-segment model following Zatsiorsky. Thirteen body landmarks (head, 2x shoulder, 2x elbow, 2x wrist, 2x hip, 2x knee, 2x ankle) were manually digitized in a 2D analysis, utilizing

only camera two positioned beside the vaulting table.

The accuracy comparison between 2D and 3D analyses for calculating peak height and flight distance was conducted by Schärer et al. (2019) and confirmed as accurate. Flight distance was defined as the difference between the horizontal take-off position of the hands (average horizontal position of the left and right wrist) and the horizontal position of the feet (average horizontal position of the left and right ankle) at landing.

The evaluation was conducted for vaults categorized into specific vault groups: Forward handspring with stretched somersault and turns, Forward handspring with tucked/piked somersault, Kasamatsu/Tsukahara, and Yurchenko. The subdivision of the Forward handspring was made based on the further reduction of angular momentum during take-off from the vaulting table. The ten vaults with the highest qualitative scores (Execution-Score as determined by official judges) and a difficulty value of >= 4.8 (Fédération Internationale de Gymnastique, 2022) per vaulting group were selected. This resulted in the following distribution of vaults across the vault groups (Table 1) and the E-scores for each vault group (Table 2).

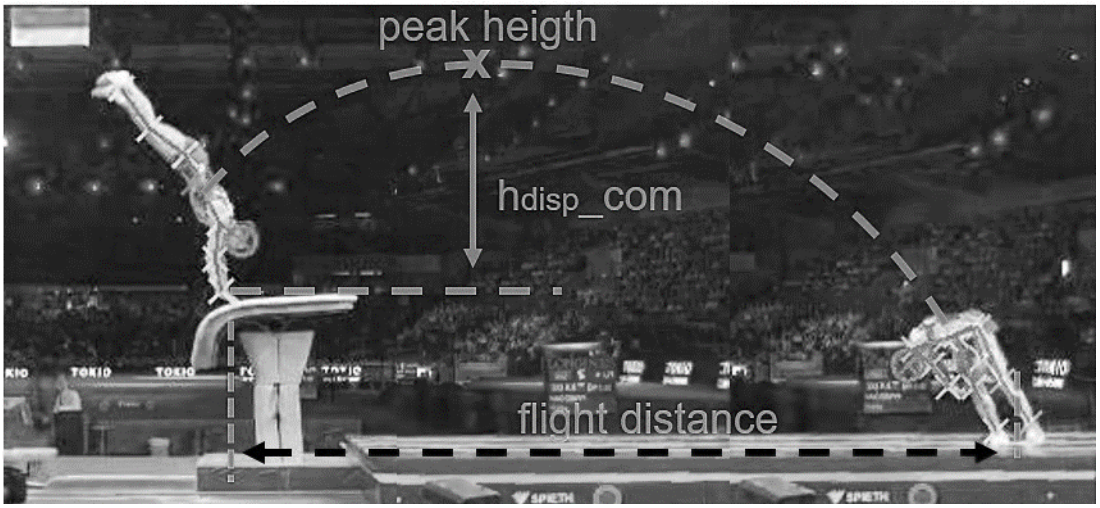

Fig. 3 Calculation of peak height (h_{peak_com}) (related to CoM coordinates) between release from the table and landing distance (hands: take-off from table and ankle at landing)

Table 1
Absolute (N) and relative (%) [of 308 vaults] distribution of vaults in the individual vault groups

vault group	**N (WC)**	**N (D>=4.8)**	**% (D>=4.8)**
Kasamatsu/Tsukahara	196	176	57.1
Yurchenko	41	35	11.4
Forward handspring tucked/piked somersault	50	49	15.9
Forward handspring stretched somersault	23	19	6.2

Table 2
Descriptive statistics of the selected E scores for the vault groups (N=10)

vault group	min	max	mean	sd
Kasamatsu/Tsukahara	9.266	9.466	9.342	.060
Yurchenko	9.200	9.466	9.311	.079
Forward handspring tucked/piked somersault	9.000	9.533	9.229	.178
Forward handspring stretched somersault	8.900	9.300	9.079	.153

All statistical analyses were conducted using SPSS 23 software (SPSS Inc., Chicago, IL). Data normality was assessed using the Shapiro–Wilk test. Descriptive statistics, including median (MD) with interquartile range (IQR) and minimum and maximum values, were computed for each variable across the individual vault groups. Given that the majority of the data did not follow a normal distribution based on the Shapiro–Wilk test and the small sample size, correlations between the reaction forces and flight parameters were evaluated using Spearman's ρ. A significance level of $p < 0.05$ was set. To mitigate the issue of multiple comparisons and reduce Type I errors, the Bonferroni-Holm correction was employed for multiple testing. The classification scheme proposed by Cohen (1988) was used to interpret the effect sizes, where correlations of 0.10–0.29 were considered small, 0.30–0.49 moderate, and ≥ 0.50 large.

RESULTS

In the analysis, maximum forces were calculated up to a median (MD) of 5.44 [IQR 4.89-6.38] times body weight (BW) for the Forward handspring tucked somersault vault group. This was followed by the Yurchenko group at 4.64 [3.93-4.88] times BW, Forward handspring stretched somersault at 4.00 [3.07-5.76] times BW, and Tsukahara/Kasamatsu at 3.96 [3.12-4.37] times BW. The highest force components were measured for the Forward handspring (tucked), with maximum horizontal forces at 4.43 [3.89-5.08] times BW and vertical forces up to 3.89 [3.40-3.90] BW. The h_{peak_com} across all vault groups ranged from 2.66 [2.57-2.79] to 2.91 [2.85-2.96] meters. The median flight distance was 3.59 [2.92-4.04] meters for the Tsukahara/Kasamatsu vault group. The greatest vertical impulses were observed for the Forward handspring (tucked) at 93.46 [71.13-102.20] Ns. A horizontal velocity deduction of 2.28 [3.10-2.14] $m \cdot s^{-1}$ was determined for Tsukahara/Kasamatsu vaults (Tab 3).

The following presentation of results is based on the vault groups. The parameter correlations are presented for each vault group. Non-relevant correlations of individual parameters based on their direct mathematical relations (for example h_{peak_com} and h_{disp_com}) were discarded.

Vault group 1a – Forward handspring with tucked/piked somersault

For the vault group performing forward handspring with tucked/piked somersaults, no significant correlation was found between the force parameters ($Fres_{max}$, Fx_{max}, and Fz_{max}) and flight altitude or distance. However, there were significant high correlations observed between $Fres_{max}$ and Fx_{max} (Spearman's $\rho = 0.83$, $p = 0.003$) and between $Fres_{max}$ and Fz_{max} (Spearman's $\rho = 0.83$, $p = 0.002$) (Table 4).

Table 3
Descriptive statistics of the selected sample of vaults per vault group

	Forw. handspring (tucked)		Forw. handspring (stretched)		Tsukahara/ Kasamatsu		Yurchenko	
	MD	**IQR**	**MD**	**IQR**	**MD**	**IQR**	**MD**	**IQR**
$Fres_{max}$ [BW]	5.44	4.89-6.38	4.00	3.07-5.76	3.96	3.12-4.37	4.64	3.93-4.88
Fx_{max} [BW]	4.43	3,89-5.08	3.15	2.55-4.77	3.41	2.54-4.04	3.53	3.38-4.02
Fz_{max} [BW]	3.89	3.40-3.90	2.56	1.85-3.87	2.87	2.40-3.36	3.09	2.73-3.66
pz [Ns]	93.46	71.13-102.20	48.16	24.27-78.39	41.88	37.38-59.12	81.33	71.69-92.72
h_{peak_com} [m]	2.91	2.85-2.96	2.75	2.53-2.82	2.66	2.57-2.79	2.80	2.74-3.29
h_{disp_com} [m]	0.89	0.82-0.96	0.74	0.53-0.93	0.59	0.53-0.73	0.69	0.64-0.77
flight distance [m]	3.62	3.31-4.12	3.50	3.12-3.80	3.59	2.92-4.04	3.11	3.04-3.29

Table 4
*Correlation and significance for the parameters of the vault group Forward handspring with tucked/piked somersault (*correlation is significant at the 0.05 level)*

	$Fres_{max}$	**Fx_{max}**	**Fz_{max}**	**h_{peak_com}**	**flight distance**	**h_{disp_com}**
$Fres_{max}$		0.83*	0.86*	0.36	-0.24	0.71
Fx_{max}			0.65	0.22	-0.30	0.72
Fz_{max}				0.40	0.06	0.41

Vault group 1b – Forward handspring with stretched somersault

In the vault group performing forward handspring with stretched somersaults, $Fres_{max}$ (Spearman's $\rho = 0.89$, $p = 0.000$), Fxmax (Spearman's $\rho = 0.96$, $p = 0.000$), and Fz_{max} (Spearman's $\rho = 0.81$*, $p = 0.004$) exhibited significant high correlations with flight altitude. Moreover, these force parameters ($Fres_{max}$ (Spearman's $\rho = 0.90$, $p = 0.000$), Fx_{max} (Spearman's $\rho = 0.91$, $p = 0.000$), and Fz_{max} (Spearman's $\rho = 0.89$*, $p = 0.000$)) showed significant high correlations with h_{disp_com}. $Fres_{max}$ demonstrated a significant high correlation with both Fx_{max} (Spearman's $\rho = 0.95$, $p = 0.000$) and Fz_{max} (Spearman's $\rho = 0.92$, $p = 0.000$). Additionally, a significant high correlation was observed between Fx_{max} and Fz_{max} (Spearman's $\rho = 0.85$, $p = 0.020$) (Table 5).

Vault group 2 – Tsukahara/Kasamatsu
For this vault group,

There were significant correlations among the force parameters. Specifically, there were notably high correlations between $Fres_{max}$ and Fx_{max} (Spearman's $\rho = 0.96$, $p = 0.000$), $Fres_{max}$ and Fz_{max} (Spearman's $\rho = 0.90$, $p = 0.000$), and between Fx_{max} and Fz_{max} (Spearman's $\rho = 0.88$, $p = 0.001$). Furthermore, a significant high correlation was observed between Fz_{max} and flight distance (Spearman's $\rho = 0.72$, $p = 0.002$) (Table 6).

Vault group 3 – Yurchenko

For this group of vaults no significant correlations can be demonstrated (Table 7).

Table 5
*Correlation and significance for the parameters of the vault group Forward handspring with stretch somersault (*a correlation becomes significant at the 0.05 level)*

	$Fres_{max}$	Fx_{max}	Fz_{max}	h_{peak_com}	flight distance	h_{disp_com}
$Fres_{max}$		0.95*	0.92*	0.89*	0.13	0.90*
Fx_{max}			0.85*	0.96*	0.06	0.91*
Fz_{max}				0.81*	0.05	0.89*

Table 6
*Correlation and significance for the parameters of the vault group Tsukahara/Kasamatsu (*a correlation becomes significant at the 0.05 level)*

	$Fres_{max}$	Fx_{max}	Fz_{max}	h_{peak_com}	flight distance	h_{disp_com}
$Fres_{max}$		0.96*	0.90*	0.18	0.56	0.31
Fx_{max}			0.88*	0.02	0.52	0.21
Fz_{max}				0.12	0.72	0.30

Table 7
*Correlation and significance for the parameters of the vault group Yurchenko (*a correlation becomes significant at the 0.05 level)*

	$Fres_{max}$	Fx_{max}	Fz_{max}	h_{peak_com}	flight distance	h_{disp_com}
$Fres_{max}$		0.49	0.62	-0.20	-0.32	-0.37
Fx_{max}			-0.14	-0.49	-0.39	-0.29
Fz_{max}				0.34	-0.08	0.17

DISCUSSION

The results of the presented study show relative forces of up to 5.7 times body weight for $Fres_{max}$ in successful handsprings with stretched somersaults. In the horizontal direction, forces of 4.6 BW were measured during the take-off from the vaulting table for the forward handspring. These findings align with those of Schweizer (2003) and Knoll et al. (2014), who also reported horizontal forces of approximately 3000 N, equivalent to around 5 times BW for the forward handspring. As anticipated, the highest vertical and horizontal forces were measured during the forward handspring with tucked/piked somersaults. Interestingly, the Yurchenko vaults also exhibited resulting forces up to 4.4 BW, with horizontal forces being 3.6 times the body weight and vertical forces at 2.9 BW. It was previously assumed that Yurchenko vaults would generate higher vertical than horizontal forces during take-off from the vaulting table.

Looking at the peak height of com (h_{peak_com}) parameter, the forward handspring with tucked/piked somersault with 2.91 m shows the highest h_{peak_com}. Consequently, this vault group has a substantially higher hpeak_com than the forward handspring with stretch somersault with 2.75 m. This could result from the high push-on effect of the forward handspring with tucked/piked somersault.

With the Tsukahara/Kasamatsu vaults, an average h_{peak_com} of around 2.66 m has been confirmed, as these vaults had a lower take-off angle from the table than those of the other groups. In his investigations, Schaerer et al. (2019) was able to determine h_{peak_com} data of 2.87 m for handspring forward and 2.68 m for Tsukahara/Kasamatsu. Accordingly, the method used in this study appears to achieve similar values.

At the beginning of this investigation, it has been expect that the more forces gymnasts used to take- off the table, the higher and farther gymnasts would fly. This could not be confirmed in the statistical verification.

Instead, the athlete's technique seems to have a decisive influence on the flight height and flight distance.

However, it has to be considered that for forward handspring with tucked/piked somersault and stretched somersault, the horizontal force shows a statistical relationship to the h_{peak_com}.

In further investigations, a comparison of the h_{peak_com} calculated using kinemetry and the flight altitude calculated using dynamometry was also conducted. If a physical relationship can be proven between these methods for the vaulting table, the method of the dynamometry could be used for providing immediate information about the h_{peak_com} and flight distance based on the reaction forces. It is known that there is a physical relationship. However, the accuracy of the calculation methods needs to be verified.

Furthermore, the geometry and physical properties such as damping of the vaulting table should be considered. Given the physical background, these parameters appear to influence influence a) the athletic technique and b) thus, the execution, height, and width of the vault. However, the question posed in the title – whether maximum forces result in maximum peak height and distance - cannot be confirmed. Athletic technique, run-up velocity, and the optimization between reaction force and take-off angle play a decisive role in determining the maximum peak height and flight distance.

CONCLUSION

The study investigated the statistical correlation of the forces during the take-off phase at the vaulting table on the peak height of center of mass and the flight distance. For this purpose, high-level vaults of the World Championship of 2019 have been investigated. The forces were measured at the vault using a specially developed force measuring unit. 2-d kinemetry has been used to evaluate h_{peak_com} and flight distance. The analysis shows a correlation only for the group of forward handsprings. In further investigations, the optimization of angular momentum and h_{peak_com} should also be included in the considerations of the h_{peak_com} and flight distances.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest whatsoever

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ENHANCING TEAMGYM PERFORMANCE WITH POWER TRAINING

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Abstract

Previous studies have highlighted a strong relationship between mechanical lower limb muscle function and TeamGym performance, specifically in terms of difficulty scores in trampette and tumbling disciplines. To date, no intervention study has explored whether enhancing lower limb muscle function can translate to improved TeamGym performance. We recruited eleven national-level TeamGym athletes (four males, seven females) for a quasi-experimental intervention spanning six weeks. The regimen comprised strength training sessions thrice weekly, emphasizing power and maximum strength. Pre- and post-intervention assessments included countermovement jumps, drop jumps, leg press power, 20m sprints, jump and reach, as well as video analyses of trampoline and tumbling performances. In line with prior research, our study uncovers significant correlations between physical test outcomes and TeamGym performance. Notably, leg press power exhibited a robust association with trampoline performance ($r=0.95$, $p<0.001$), while drop jump results correlated strongly with tumbling performance ($r=0.72$, $p<0.05$). Post-training, only the intervention group displayed a statistically likely uptick in leg press power. Additionally, the intervention group saw an average increase of 0.15 ± 0.2 points in difficulty, contrasting with the control group's negligible change (0.0 ± 0.2).Given the limited sample size in this preliminary pilot study, the results warrant cautious interpretation. Nonetheless, they resonate with prior findings, suggesting that augmenting an athlete's mechanical lower limb muscle function through targeted strength and power training can beneficially influence national-level TeamGym performance.

Keywords: *TeamGym, Power, Training, Performance, Intervention.*

INTRODUCTION

Gymnastics encompasses a range of disciplines, including sports acrobatics, rhythmic sports gymnastics, and artistic gymnastics. TeamGym (TG) is a specific gymnastics discipline where athletes compete in trampoline, tumbling, and floor exercises. A team typically comprises between 6 and 12 athletes. Athletes' performances are judged based on difficulty level, style, and composition (De Pero et al., 2021). TG has been gaining popularity, with European Championships held biennially since 1993. Despite its growing appeal, research specifically focused on TG performance remains limited (De Pero et al., 2021; Hansen, Hvid, Aagaard, & Jensen, 2019).

Similar to other gymnastic disciplines, TeamGym performance heavily relies on the ability to execute movements rapidly (De Pero et al., 2021; Hansen et al., 2019). Among the three disciplines in TG, the trampoline and tumbling apparatus are most dependent on muscular function (Elbæk, 1993). To improve performance in the trampoline or tumbling, athletes can enhance either the style or difficulty level of their skills. The ability to execute high-level skills in these apparatuses depends on the time available in the air (Hansen et al., 2019). Consequently, increasing the time in the air requires elevating the vertical impulse (force x time) generated during the push-off phase (Jemni & Sands, 2017). Achieving such an increase in impulse can be influenced by various factors. Arguably, optimizing the technique to achieve the highest impulse, such as hitting the apparatus at an optimal angle, is one of the most crucial factors (Jemni & Sands, 2017). However, for well-trained athletes who have nearly perfect technique after years of training, other factors to enhance the impulse also become significant (De Pero et al., 2021; Elbæk, 1993; Hansen et al., 2019; Jemni & Sands, 2017).

The use of springs in TG apparatuses allows for the force and energy applied to the apparatus to be temporarily stored in the spring. This energy then acts back on the athletes, propelling them into the air (Jemni & Sands, 2017). This spring mechanism implies that the highest jump heights are achieved by applying the maximum forces the athlete can tolerate, while staying within the mechanical limits of the springs (Jemni & Sands, 2017). In TG, athletes utilize a 15m long run-up track to build momentum, calculated as velocity multiplied by mass (Jemni & Sands, 2017). Therefore, the muscular capacity to accelerate the body along the 15m run-up track, coupled with the leg muscles' ability to handle the forces from the accumulated momentum, is crucial for TG athletes (Hansen et al., 2019).

To the best of the author's knowledge, only one study has explored the influence of muscular capacities on TG performance. Hansen et al. (2019) examined the relationship between mechanical lower limb muscle function and performance among a group of TG athletes. Participants underwent a series of tasks to assess their muscular function and reported their maximal performance levels on the trampoline and tumbling apparatuses. As anticipated, significant associations were found between measures of mechanical lower limb muscle function and TG performance. However, given that the study was cross-sectional in nature, caution is warranted when drawing causal inferences from these findings. To further our understanding and expand on current knowledge, an experimental study targeting muscular capacity is highly warranted (Hansen et al., 2019).

The aim of the present study was therefore to investigate whether improving muscular power would increase performance in TeamGym. We hypothesized that i) TG performance would be associated with measures of physical function and ii) an increase in muscular function due to training would result in improved TG performance.

METHODS

The sample consisted of 11 TeamGym athletes (age: 17.6 ± 1.1 years, weight: 63.1 ± 11.5 kg, height: 168.4 ± 11.0 cm) competing at the national level (4 males, seven females). Two participants could not complete the study, one due to an injury during gymnastics training and the other due

to a quarantine period in connection with COVID-19. Consequently, nine participants completed the post-tests. Finally, the intervention group consisted of four subjects (three girls and one boy), and the control group consisted of five subjects (three girls and two boys).

The intervention group followed a structured power training program (see Table 1) over six weeks, consisting of three sessions weekly.

Table 1:
Training program for the intervention group

	Exercise	Reps	Set	Pause	Load / comment
Session 1	One-legged box jump	4	3	3 min	Bodyweight
	Drop jump up to box	5	3	3 min	Bodyweight
	Sprint 20m	3	2	3 min	Max effort
	Sprint 15m + resistance	5	2	3 min	Pushing plyo-boxes
Session 2	Drop jump to broad jump	4	3	3 min	Bodyweight
	Loaded squat jumps	5	3	3 min	20 - 40kg max effort
	Sprint 20m	3	2	3 min	Max effort
	Jump rope, 1 foot	60s	2	3 min	Jump Rope
Session 3	Back squat	5	3	3 min	1-2 reps in reserve
	Split squat	4	3	3 min	1-2 reps in reserve
	Bulgarian split squat	5	3	3 min	1-2 reps in reserve
	Hip thrust	5	3	3 min	1-2 reps in reserve

The three sessions included different exercises that focused on plyometric and high load strength training of the lower extremities, commonly recommended to increase power and jumping ability in athletes (Bauer et al., 2019). When the training program was created, the sport's uniqueness was kept in mind, using exercises that strengthen and challenge the movements one performs on the trampoline and tumbling. The training sessions were implemented in connection with the weekly gymnastics sessions to ensure that all practitioners in the intervention group completed the interventions correctly. The practitioners were asked to make corrections and received good follow-up during the six weeks of the intervention. The athletes were familiar with earlier exercises, making it easier to complete the training program. The control group performed basic training as usual at the end of the gymnastics sessions. The sessions were of the same type as before the project started. In exercises such as push-ups, unloaded jump squats, and burpees, bodyweight-inspired sessions with no external loads were used. The intensity of the heavier exercises was regulated by utilizing reps in reserve, with rep ranges aligning with a relative intensity of 70% 1RM and above. The training in the two groups was thus different, with different focus during the six weeks the intervention lasted.

Vertical jumps were performed following a protocol where participants kept their hands on their hips to standardize the movement and focus the effort on lower body. The assessment comprised two sets, each consisting of three jumps, to ensure reliability and allow athletes to demonstrate their maximal jumping capability. The

highest jump from these six attempts was recorded for analysis. Jump heights were precisely measured using a force plate (Muscle lab; Ergotest AS, Porsgrunn, Norway)

Drop jumps were executed with hands on the hips. The participant stepped down from a 29 cm high box and was instructed to jump as high as possible, with the slightest contact time on the force platform. Two series of three trials were conducted, with the best result recorded. Jump height and the reactive strength index (Jump height/contact time) were measured using a force plate (Muscle lab; Ergotest AS, Porsgrunn, Norway).

The seated leg press was conducted using a "Keiser A300 horizontal leg press dynamometer" (Keizer Sport, Fresno, CA). Power results were obtained from a 10-repetition test with incremental loads. In this test, participants performed ten repetitions, exerting maximum effort as the load increased. The seat position was individually adjusted to ensure the femur was vertical, aligning with a knee joint angle at 80 ° - 90 °. Participants were instructed to fully extend both legs with maximal effort in each repetition. For further details regarding the apparatus, see Lindberg, Eythorsdottir, et al., 2021.

20-meter sprints were timed using a gate system that measured the time from 0-30m with 5-meter intervals (Muscle lab; Ergotest AS, Porsgrunn, Norway). The timing initiation was registered by a photocell placed at the start line, aligned with the participant's front foot. For this study, the focus was on the time taken to cover the 0-20 meter distance, which served as the primary measure for further analysis. The subjects completed three trials with a 3-minute rest period between them. If there was improvement in the third trial, an additional attempt was allowed.

The Jump and Reach test involved participants using a self-selected run-up to jump off one foot and reach the highest point possible on the apparatus. Two series of three trials were completed, with the average of the two best trials recorded. The "Vertec Vertical Jump Tester" (JUMPUSA; Sunnyvale, CA 94089, USA) was used for this assessment.

Video analysis was conducted during regular gymnastics training. Athletes performed their best competition routines on both the trampoline and tumbling, with simultaneous filming taking place. Subsequently, videos were analyzed in a blinded fashion — the evaluator was unaware of whether the videos were recorded before or after the intervention. A qualified judge assessed each athlete based on the difficulty (degree of difficulty) and execution, adhering to current TeamGym regulations (Turnforbund, 2019). The difficulty level of the routine (D-score) was calculated by summing the scores for all elements, which starts at zero with no upper limit. Execution (E-grade) ranged from 0 to 10, with athletes beginning at 10 points and having points deducted (typically in tenths) based on their performance throughout the routine (Turnforbund, 2019).

The present study utilized a quasi-experimental design, marked by the deliberate manipulation of an independent variable (the structured power training program) without randomizing participants into intervention and control groups. This design was selected due to the practical constraints of working with a specialized, competitive athlete population. Logistical and ethical considerations made randomization unfeasible. While this approach enabled an investigation into the

effects of the power training program on TeamGym performance, it also recognized the limitations stemming from the absence of random assignment.

The Pearson product-moment correlation coefficient (Pearson r) was employed to ascertain the relationships between the physical and TeamGym performance tests. These analyses pooled data from all subjects at the pre-test, rather than within individual groups, to offer a comprehensive overview of correlations across the entire sample. The Pearson's r coefficients were categorized as follows: 0.00–0.09 trivial; 0.10–0.29 small; 0.30–0.49 moderate; 0.50–0.69 large; 0.70–0.89 very large; 0.90–0.99 nearly perfect; 1.00 perfect, as previously defined (W. G. Hopkins, S. W. Marshall, A. M. Batterham, & J. Hanin, 2009).

Effects were assessed using non-clinical magnitude-based inferences (MBD), a method suitable for small samples (W. Hopkins, S. Marshall, A. Batterham, & J. J. M. S. i. S. E. Hanin, 2009). The magnitude of changes within and between sessions was evaluated by standardization (mean change/difference divided by baseline SD of all subjects). The resulting standardized effect was assessed using a modification of Cohen's (1992) scale: <0.2 trivial; 0.2–0.6 small; 0.6–1.2 moderate; >1.2 large (W. Hopkins et al., 2009).

To infer clinically meaningful effects in the studied population, effects were expressed as probabilities of harm or benefit relative to the smallest worthwhile change (0.2 of SD; W. Hopkins et al., 2009). A clear change within or difference between pre-post or groups indicated an effect almost certainly not harmful (<0.5% risk of harm) and potentially beneficial (>25% chance of benefit).

The effect was presented as the difference or change with the highest probability, qualitatively categorized as follows: 25–75% possibly; 75–95% likely; 95–99.5% very likely; >99.5% most likely (W. Hopkins et al., 2009). Descriptive data are reported as mean ± SD. All statistical analyses were conducted using a customized Microsoft Excel spreadsheet (W. Hopkins et al., 2009).

RESULTS

For all participants combined, a large to very large relationship was observed between the physical performance tests and TeamGym performance (D-score) on the trampoline (r: 0.72 to 0.95, $p<0.05$) and tumbling apparatus (r: 0.56 to 0.72, $p<0.05$). Weaker correlations were found between physical performance and TeamGym E-scores (r: 0.06 to 0.72) (Table 2).

Table 2:
Correlation table comparing TeamGym performance with physical performance

	Reach (cm)	Cmj (cm)	Drop-jump (RSI)	20m time (s)	20m speed (m/s)	Power (w/kg)
Tumbling - (D)	0.56#	0.71*	0.72*	-0.55#	0.55#	0.67*
Tumbling - (E)	-0.32	0.06	-0.10	0.08	-0.15	0.06
Trampette - (D)	0.72*	0.92***	0.45	-0.87***	0.88***	0.95***
Trampette - (E)	0.55#	0.53#	0.26	-0.63*	0.72*	0.61*
Difficulty – Average	0.65*	0.87***	0.62*	-0.77**	0.77**	0.87***

*D: Difficulty, E: Execution, cm: Centimeter, s: Seconds, m/s: meter per second, W/kg: watts/bodyweight. RSI: Reactive strength index, Reach: Jump and Reach test, Power: Leg press power, Cmj: counter movement jump, *** p<0.001 ** p<0.01 * p<0.05, # p<0.10. n=11 from the pre-test.*

Table 3: Pre and post values for both groups, for all measurements.

		Pre			Post			Change					Individual			Group-differences (Int-Con)			
Test:	**Group (n=)**	**Mean**	**±**	**SD**	**Mean**	**±**	**SD**	**Δ**	**±**	**SD**	**ES**	**Non-clinical MBI**		**↓ / - / ↑**		**Mean**	**ES**	**Non-clinical MBI**	
Jump and Reach (cm)	Int (4)	279.9	±	17.5	280.8	±	17.4	0.87	±	0.6	0.04	Trivial	(Most likely)	0	4	0	-3.1	-0.11	Trivial	(likely)
	Kon (5)	273.2	±	38.1	277.2	±	37.2	4.00	±	4.2	0.16	Trivial	(likely)	0	3	2				
Cmj (cm)	Int (4)	36.7	±	9.4	37.7	±	8.6	1.05	±	1.3	0.16	Trivial	(possibly)	0	3	1	3.0	0.50	Small	(likely ↑)
	Kon (5)	33.6	±	3.5	31.7	±	2.9	-1.90	±	3.1	-0.29	Small	(possibly ↓)	2	3	0				
Drop jump (RSI)	Int (4)	203	±	36.5	193	±	45	-10.2	±	49	-0.26	Small	(unclear)	2	0	2	-3.7	-0.09	Trivial	(unclear)
	Kon (5)	172	±	52.9	165	±	20	-6.5	±	38	-0.17	Trivial	(unclear)	2	1	2				
20 m time (s)	Int (4)	3.03	±	0.3	3.04	±	0.3	0.01	±	0.0	0.04	Trivial	(likely)	1	2	1	0.05	0.23	Small	(possibly ↑)
	Kon (5)	3.13	±	0.2	3.09	±	0.2	-0.04	±	0.1	-0.17	Trivial	(possibly)	2	3	0				
20 m velocity (m/s)	Int (4)	7.8	±	1.0	7.8	±	1.0	0.03	±	0.1	0.04	Trivial	(Very likely)	0	1	3	0.0	-0.05	Trivial	(Very likely)
	Kon (5)	7.5	±	0.6	7.6	±	0.6	0.07	±	0.1	0.09	Trivial	(Very likely)	1	0	4				
Leg press Power (w/kg)	Int (4)	18.8	±	4.6	19.7	±	4.8	0.95	±	0.9	0.29	Small	(likely ↑)	0	1	3	0.6	0.19	Trivial	(possibly)
	Kon (5)	16.3	±	2.3	16.7	±	2.8	0.38	±	1.0	0.11	Trivial	(likely)	1	3	1				
Tumbling - (D))	Int (4)	1.3	±	0.6	1.4	±	0.6	0.06	±	0.0	0.15	Trivial	(likely)	0	4	0	0.1	0.24	Small	(possibly ↑)
	Kon (5)	0.7	±	0.2	0.7	±	0.2	-0.03	±	0.1	-0.07	Trivial	(likely)	1	4	0				
Tumbling - (E)	Int (4)	9.4	±	0.3	9.1	±	0.7	-0.30	±	0.5	-0.41	Small	(likely ↓)	2	2	0	-0.9	-1.12	Moderate	(Very likely ↓)
	Kon (5)	8.3	±	1.2	9.0	±	0.4	0.63	±	1.1	0.86	Moderate	(likely ↑)	0	3	2				
Trampette - (D)	Int (4)	1.2	±	0.7	1.5	±	1.0	0.23	±	0.3	0.47	Small	(likely ↑)	0	2	2	0.2	0.48	Small	(likely ↑)
	Kon (5)	0.8	±	0.3	0.8	±	0.3	0.02	±	0.2	0.04	Trivial	(likely)	1	3	1				
Trampette - (E)	Int (4)	9.2	±	0.6	9.1	±	0.4	-0.14	±	0.5	-0.30	Small	(unclear)	2	0	2	-0.2	-0.50	Small	(unclear)
	Kon (5)	9.1	±	0.5	9.2	±	0.3	0.09	±	0.4	0.19	Trivial	(unclear)	2	0	3				
Difficulty- Mean	Int (4)	1.3	±	0.7	1.4	±	0.8	0.14	±	0.2	0.32	Small	(likely ↑)	0	3	1	0.1	0.37	Small	(likely ↑)
	Kon (5)	0.8	±	0.2	0.8	±	0.2	0.00	±	0.1	-0.01	Trivial	(likely)	1	3	1				

*Int: Intervention group, Con: Control-group, D: Difficulty, E:Execution, cm: Centimeter, s: Seconds, m/s: meter per second, W/kg: watts/bodyweight, RSI: Reactive strength index, SD: standard deviation, ES: Effect size, MBI: magnitude-based inferences, Qualitative interpretations follow the scale: for ES: <0.2, trivial ; 0.2–0.6, small ; 0.6–1.2, moderate ; >1.2, large . Effects follow the scale: 25–75%, possibly; 75–95%, likely ; 95–99.5%, very likely; >99.5%, most likely. Individual changes are defined as >0.2*SD.*
↓: Decrease / - no change / ↑
Increase

Only the intervention group showed a statistically likely increase in leg press power following the training period (ES: 0.29 vs 0.11 for the control group). No other statistically likely improvements were observed in the other performance measures. The intervention group exhibited an average increase of 0.15±0.2 points in difficulty for trampette and tumbling (ES: 0.32 likely increase), whereas the control group showed no change (0.0±0.2) (Table 3).

DISCUSSION

The primary aim of this study was to investigate whether an improvement in muscular power would enhance performance in TeamGym. The results demonstrate a strong relationship between the physical performance tests and performance on the trampoline and tumbling apparatuses in TeamGym. Additionally, we observed a small but likely increase in both power and difficulty value on the trampoline of the intervention group. In contrast, the control group showed no tendency to increase either power or difficulty value across any apparatus. These findings confirm and build upon previous research, suggesting that higher physical performance benefits TeamGym outcomes and that targeted muscular power training can boost TeamGym performance.

Limited research exists on the relationship between muscular power development and TeamGym performance, as highlighted in the introduction. A study similar to ours was conducted by Hansen et al. in 2019. Consistent with our findings, they identified a correlation between TeamGym performance and leg extensor power, noting a strong relationship between sprint results and trampoline performance ($r = -0.87$; $p < 0.05$). This correlation is logical, as higher sprint speeds can lead to increased jump heights on the trampoline. Additionally, Hansen et al. found a robust link between Rate of Force Development (RFD) and trampoline performance. While we didn't measure RFD directly, its close association with muscular power (McGuigan, Winchester, & medicine, 2008) aligns with our strong relationship between muscular power and trampette performance. Our study also revealed some novel insights. Notably, drop jumps, which share biomechanical and neuromuscular similarities with tumbling, showed the strongest correlation with tumbling performance. The most significant finding, however, was that the strength and power training intervention group exhibited increases in both power and TeamGym performance, a change not observed in the control group.

Table 2 highlights a significant correlation between all physical tests and the TeamGym difficulty score. Leg press power showed the strongest association with trampoline performance ($r = 0.95$; $p < 0.001$), while the drop jump was most closely linked with tumbling ($r = 0.72$; $p < 0.05$). Figure 1, derived from Table 2, depicts the relationship between difficulty value in the trampoline and leg press power (W/kg). The regression line indicates that for every 1 W/kg increase in power, the difficulty value rises by 0.15 points.

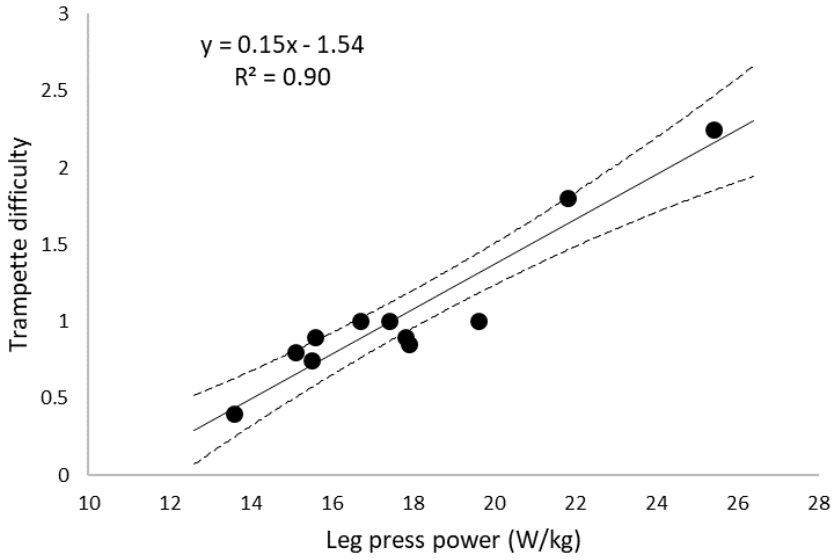

Figure 1: Correlation between trampette difficulty and leg press power. W/kg; Watts per kg bodyweight. n=11 from the pre-test.

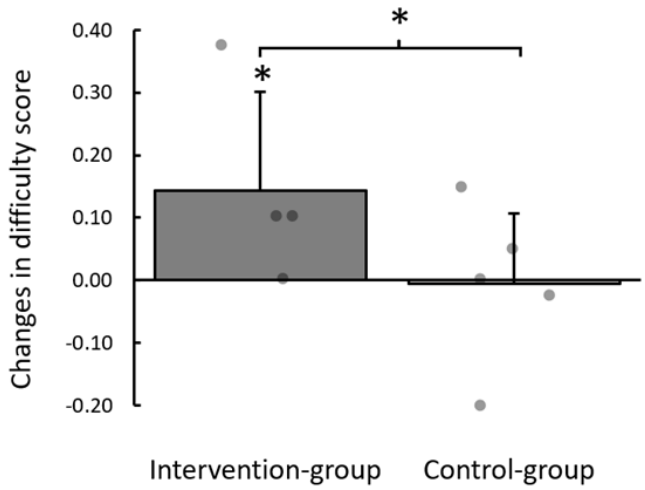

Figure 2: Changes in averaged difficulty level on trampette and tumbling apparatus. *Likely increase/ difference between groups.

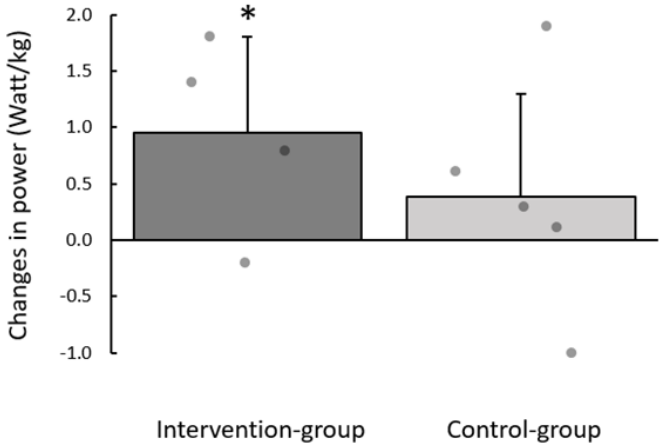

Figure 3: Changes in Leg press power after the training intervention. *Likely increase/difference between groups. W/kg; Watts per kg bodyweight

Interestingly, the intervention group saw an average increase of 0.15 points in difficulty value, whereas the control group showed no change (Figure 2). Figure 3 reveals that both groups experienced an increase in leg extensor power (W/kg), but only the intervention group's increase was statistically significant. These results suggest that enhancing muscular power can lead to an increase in the difficulty value in TeamGym performance.

The training intervention primarily impacted leg press power, while the other jump and sprint tests showed no significant changes. This limited effect, with an effect size of 0.29, could be attributed to the leg press test's higher measurement accuracy and better standardization (Lindberg et al., 2022; Lindberg, Solberg, et al., 2021). Given the predetermined positions and reduced technical variability in this test, results are less influenced by technique compared to more varied tests like drop jumps, fall jumps, and sprints (Lindberg et al., 2022; Lindberg, Solberg, et al., 2021).

The relatively short duration of the training intervention, spanning only 6 weeks, likely contributed to the modest effect size. Prior research with longer durations, ranging from 8 to 24 weeks, has reported effect sizes up to 0.8-1.0, whereas studies of approximately 6 weeks typically yield an average effect size of 0.42 (Bauer et al., 2019; Freitas, Martinez-Rodriguez, Calleja-González, & Alcaraz, 2017). Moreover, it's conceivable that the impact might have been more pronounced with athletes starting at a lower performance level than those in our study (Freitas et al., 2017).

Building on these findings and previous recommendations, it's advised that TeamGym athletes prioritize the development of muscular power, jump height, and sprint and acceleration capabilities. Hence, incorporating plyometric jump training along with heavy resistance exercises can establish a robust foundation of muscle strength and power, essential for mastering the specialized acrobatic skills integral to TeamGym performance.

CONCLUSION

This pilot study suggests that incorporating power training can yield positive effects on TG performance among national-level athletes. Given the limited number of participants in this study, it's essential to interpret the results with caution. However, aligning with the current findings and existing literature, we advocate for integrating power training into the foundational conditioning regimen for TeamGym athletes. Specifically, a blend of heavy-load and low-load plyometric exercises appears to be a potent approach for enhancing power and jump-related performance among national-level athletes, crucial for optimal TG outcomes. Future research endeavors should aim for larger sample sizes to achieve more broadly applicable and generalizable results.

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THE EFFECTS OF GYMNASTICS TRAINING ON FLEXIBILITY AND STRENGTH IN CHILDREN

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Abstract

The aim of this study was to examine the effects of gymnastics training on flexibility and strength parameters of gymnasts. A total of 48 boys aged 5-7 years participated in this study voluntarily. Participants were randomly assigned to two groups (Experimental group n=24; age, height, weight and BMI 6.21±1.10 years, 114.18±19.98 cm, 22.38±4.09 kg, 15.85±1.59 kg/m², respectively; Control group n=24; age, height, weight and BMI (6.87±0.74 years, 114.18±19.98 cm, 22.38±4.09 kg, 15.90±2.72 kg/m², respectively). Standing Long Jump test (SLJ), Bent Arm Hang (BAH), Sit Ups in 30seconds Cruch (SUC), Sit and Reach Flexibility Test (SRF) and Static Flexibility (SF) tests were applied to the experimental and control groups. The training was applied to the experimental group three days a week for 12 weeks, each time for the duration of 90 minutes. A two-way Repeated Measure ANOVA (2×2) was used to test for interactions and main effects for time (pre-test vs. post-test) and group (experimental vs. control) on the dependent physical performance variables. Results showed that there was a statistically significant difference in the TSC and SR values of the experimental group from pre to post-tests ($p<0.01$, $d=0.95$, $p<0.01$, $d=0.75$, respectively). There were no significant differences in other parameters. According to post-test group difference results, experimental group participants performed better than those in the control group in terms of BAH, SUC, SLJ and SRF values ($p<0.02$, $d=0.780$; $p<0.04$, $d=0.614$; $p<0.00$, $d=2.11$ respectively). As a conclusion, gymnastic training program significantly improved strength and flexibility of gymnasts aged 5-7 years.

Keywords: *gymnastics, training, strength, flexibility, performance tests.*

INTRODUCTION

Artistic Gymnastics (AG) is a highly demanding sport that requires several motoric competencies at high levels within the framework of certain rules on its unique competition apparatus (Zhao et al. 2021). AG predominantly uses specific movements such as jumps, leg-arm swings and static-dynamic stances (Özer and Soslu, 2019a).

To perform certain techniques in AG properly, various combinations and repetitions of these movement groups are required (Dallas and Kirialanis, 2013). Moreover, AG athletes are expected to have sufficient flexibility in their muscles, tendons, ligaments, and joint capsules in order to perform these movements better (Özer and Soslu, 2019b; Moeskops et al. 2019). Flexibility, one of the most important motoric abilities that distinguishes AG from other sports (Sands et al. 2016), ensures the speed, quality and aesthetics of technical movements (Ivanov and Bardina 2021; Dolbysheva et al. 2022). Muscle flexibility relates to the maximum extent of motion in a joint or several joints, as well as the length of muscles that span these joints and facilitate bending movements. Individuals exhibit varying degrees of flexibility, especially in relation to variations in the length of their multi-joint muscles. Explosive power, in the same a direction, pertains to the capacity to rapidly generate intense muscle contractions in a sudden burst of activity. Studies have demonstrated that the most significant factors for a gymnast's performance are flexibility, defined as a painless range of motion (ROM), and explosive power. Douda et al. found specific morphological and physiologic features exhibited by top gymnasts, such as exceptional flexibility and explosive force. Consequently, these levels were notably elevated in elite gymnasts compared to non-elite gymnasts (Douda et al., 2002). Studies clearly indicate that flexibility of AG athletes is a significant feature that should be developed at the beginning of gymnastics training (Ivanov and Bardina, 2021).

The preschool years are a crucial period for the development of motor abilities. Thus, it is appropriate that early childhood education standards emphasize that the development and enhancement of motor skills should be a fundamental component of educational programs. While children may naturally develop basic motor skills as they grow, their full mastery of these skills can only be achieved in an environment that is suitable for their development (Gagen and Getchell, 2006). This environment should offer encouragement, opportunities for focused practice, and stimulating physical conditions that allow for the use of skills in various contexts. When it comes to enhancing children's motor skills, educators should consider the individual qualities of each child within a physical and social setting while engaging them in tasks that have specific objectives and require appropriate equipment. In this sense, two important points stand out. First, the preschool period is described as the best time to start flexibility and strength training. Learning various skills (Jemni et al., 2011), perfecting them (Sawczyn et al., 2016), and suddenly transitioning from a dynamic movement to a static one (Prassas et al., 2006; Price, 2014) are only possible in the presence of sufficient strength (Moeskops et al., 2019). Considering AG training, athletes perform more than 20 complex jumping skills during the floor series, pull-ups, rings, parallel bars, and uneven bars series (Marinšek and Pavletič, 2020). During these series of movements, athletes' legs need sufficient strength to tolerate forces that exceed their body weights, compounded by gravity and their own body mass (Gittoes and Irwin, 2012). Studies in the literature have demonstrated that developmentally appropriate strength training at an early age provides adequate and necessary strength (Gallahue and Ozmun, 2005). According to studies, children show significantly better improvements in explosive leg strength,

upper body strength, abdominal muscle strength, endurance, and flexibility after participating in developmentally appropriate training (Madić et al., 2018). Especially regarding fundamental movement skills (e.g., running, jumping, and throwing), which children are expected to perform better before school age, the movement patterns applied in training become more prominent (Takamoto et al., 2003; Nakamura et al., 2011).

Thus, for athletes to perform different movement patterns that require various qualities, they need to make effective and efficient physical preparations (Kochanowitz et al., 2010; Lamošová et al., 2021). Other factors include the age at which athletes begin AG and compete (Sawczyn et al., 2016). Moreover, it is imperative for gymnasts to undergo regular training sessions on advanced technical movements to enhance their performance and participate in competitions (Kochanowicz et al., 2009; Clowes and Knowlesvol, 2013). The aim of this study was to investigate the impact of gymnastics training on the flexibility and strength parameters of gymnasts.

METHODS

The participants of the study were 48 children who voluntarily agreed to participate. Participants in the Experimental Group (EG) (n=24) had the following characteristics: age, height, weight, and body mass index (BMI) were 6.21 ± 1.10 years, 114.18 ± 9.98 cm, 22.38 ± 4.09 kg, and 15.85 ± 1.59 kg/m², respectively. In contrast, the participants in the Control Group (CG) (n=24) had the following characteristics: age, height, weight, and BMI were 6.87 ± 0.74 years, 114.18 ± 9.98 cm, 22.38 ± 4.09 kg, and 15.90 ± 2.72 kg/m², respectively. They had no chronic diseases, lower or upper extremity injuries, or medical or orthopedic problems in the hamstring, meniscus, ankle, shoulder, elbow, or wrist.

Before the data were collected, participants and their parents were informed about the benefits and possible risks of the study. An informed consent form (in line with the Declaration of Helsinki) was given to the parents of the participants to obtain their written consent for participation. The study protocol was approved by the Research Ethics Committee of Karamanoğlu Mehmetbey University (Approval No: 01-2022/12).

For anthropometric measurements children's body weights were recorded using a Gold Master GM-7175R Slim Fit brand weighing machine with a sensitivity of ±100 g, and their height was recorded using a Mesilife Mc-210 brand height meter with an error margin of ±0.5 cm.

Test of Bend-Arm Hang: In this test, participants stood under a round bar with a 2.5 cm diameter, hands shoulder-width apart, thumbs at the bottom, elbows above, with a front grip. They were assisted from their armpits until their chin rose above the bar line. The time elapsed until the jaw dropped belowthe bar was recorded. Two attempts were made, and the highest duration was recorded in seconds and split-seconds (Lamošová et al. 2021).

Test of Sit-Ups in 30 seconds Crunch: Lying on their backs, participants placed their hands together on the back of their necks, with their knees slightly pulled toward their stomachs (knees at 90 degrees flexion) and their feet completely on the mat. As they sat up, they were instructed to bring their elbows forward to touch their knees at the end of the movement. Throughout the entire movement, they were required to keep their hands joined behind their necks and ensure their shoulders touched the mat when

returning to the starting position. On the "Start" command, they repeated this movement for 30 seconds, performing as many sit-ups as possible until the "Stop" command. At the end of the test, the total number of sit-ups was recorded (Katsanis et al., 2021).

Standing long jump test: The knees were bent, with the toes just behind the line, and the feet placed shoulder-width apart. The torso was leaned forward, and both legs simultaneously leaped as far as possible, while the arms were flung forward from backward. The test was performed twice, and the best result was written in centimeters (Kiuchukov et al. 2019).

Sit and Reach Flexibility test: A test bench with a length of 35 cm and a width of 45 cm was used, the upper surface extending 15 cm outside the surface where the feet rested. Participant leaned on the soles of their feet against the upright surface of the box, with their arms extended forward without bending their knees. The flexibility test measurements of the participants were carried out without shoes, and they remained stationary for 1-2 seconds at the furthest point where they could flex with both hands. The test was repeated twice. The best result was recorded in centimeters (González et al. 2020).

Static Flexibility test: The participants lay their faces down on the flat ground with their foreheads touching the ground. They held a2.5 cm diameter round bar with their hands and extend it up over their head without bending their arms, keeping their foreheads on the ground. The highest point they could hold the bar was recorded. At the end of 3 trials, the best result was recorded in centimeters (Aslam, 2018).

The training was administered to the experimental group three days a week (Wednesday, Saturday, and Sunday) for 12 weeks, with each session lasting 90 minutes. Stretching was performed for 10 minutes after a 10-minute low-intensity warm-up run before every training session. Following the general and specific warm-up, walking and jumping movements (such as tiptoe and heel walking, closed leg, bear, and rabbit jumps) were executed. To ensure proper execution of movements, the first week focused on adaptation, with gradual introduction to the forward roll technique. Over the subsequent two weeks, backward roll, handstand roll, cartwheel, round-off, and front handspring techniques were progressively and fully integrated into the training regimen. Strength and flexibility training programs were conducted after the technical training (refer to Table 1). Children's performance tests were conducted before and after the training program, and their results were recorded. Prior to the test, the protocol was explained by an expert to the children, with a demonstration provided. Potential errors were highlighted, and methods to prevent them were explained. After anthropometric measurements, a standard warm-up was performed, including a 5-minute run, a 5-minute passive stretching, and three maximum vertical jumps. A 5-minute rest followed the warm-up session. Tests, including Standing Long Jump (SLJ), Bend-Arm Hang (BAH), Sit-Ups in 30 seconds (SUC), Sit and Reach Flexibility (SRF), and Static Flexibility (SF), were administered to both experimental and control groups. Each child underwent the test twice, with the second trial conducted after a 5-minute passive recovery from the first. The best value from the tests was recorded. All tests were conducted at the same time of day (14:00-16:00) under standard environmental conditions (26±2°C and 75±4% relative humidity) and in the same order.

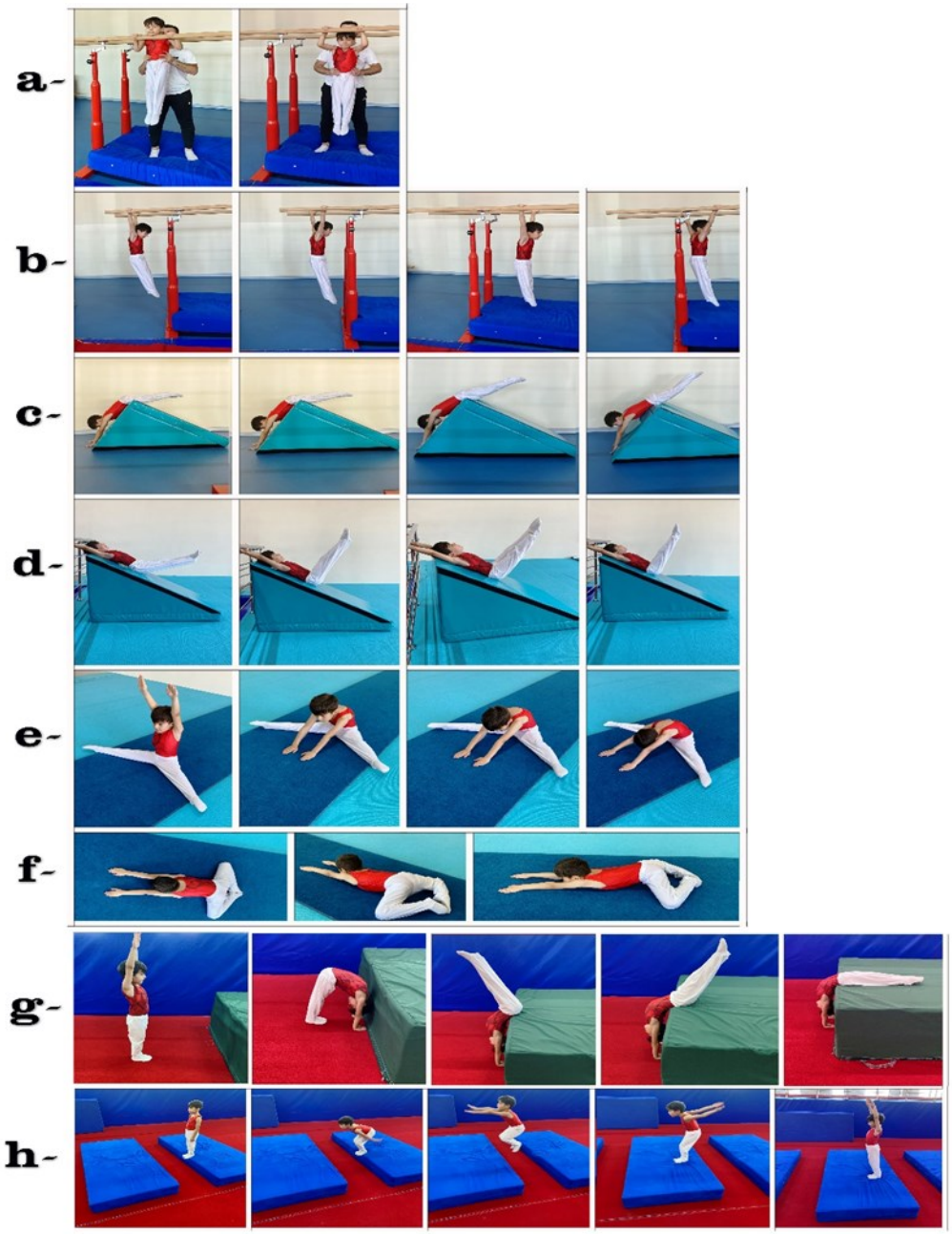

Figure 1. **a-**Assisted arm pull up bar **b-**Parallel bar hoist walking **c–**Reverse leg raise on cheese mat **d-**Leg raise on cheese mat **e–**Eagle leg stretch forward **f-**Squashed frog **g-**Bridge back from high mat **h-**Double leg jump between mats

Table 1
Training program

Week	Main Training	Actions	Set/ Repeat
1-2	Forward roll: Preparatory exercises to forward roll, assisted cradle rocking, cradle roll-off exercises, Incline assisted/unassisted forward roll, Forward roll assisted from elevation, Forward roll from elevation assisted/unassisted, forward roll exercises on flat ground, unassisted forward rolls, Backward roll entry exercise, assisted cradle, cradle roll-off exercises	Parallel bar hoist walking/ Leg raise on cheese mat /Reverse leg raise on cheese mat/Assisted arm pull up bar/ Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	2x3
3-4	Backward roll: Inclined assisted/unassisted backward roll, Assisted/unassisted backward rolls from elevation, Assisted/unassisted backward rolls on flat ground, Handstand work, robot exercises, Assisted/unassisted handstand exercises on the wall, Assisted/unassisted forward lunge exercises	Parallel bar hoist walking/Leg raise on cheese mat/Reverse leg raise on cheese mat/Assisted arm pull up bar/Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	2x4
5-6	Handstand: Assisted/unassisted handstand exercises on the wall, Assisted/unassisted handstand rolls by stepping on the wall, Assisted/unassisted handstand rolls from elevation, Inclined Assisted/unassisted handstand rolls, Assisted/unassisted handstand rolls on flat ground, Repetition of previous technical skills (Forward and backwards rolls)	Parallel bar hoist walking/Leg raise on cheese mat/Reverse leg raise on cheese mat/Assisted arm pull up bar/Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	3x4
7-8	Round-off: Assisted/unassisted hoop work round off exercises on the gymnastic beam, Inclined Assisted/unassisted hoop work round off exercises, Vertical assisted/unassisted hoop work from the pyramid frame, Round-off: Assisted/unassisted hoop work on the curved line, Assisted/unassisted hoop work on flat floor Cartwheel: assisted/unassisted single leg crossing card exercises on the gymnastic beam	Parallel bar hoist walking/Leg raise on cheese mat/Reverse leg raise on cheese mat/Assisted arm pull up bar/Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	4x4
9-10	Cartwheel: Inclined Assisted/unassisted cartwheel exercises, Vertical assisted/unassisted cartwheel exercises from the pyramid frame, Assisted/unassisted cartwheel exercises on the curved line, Assisted/unaided cartwheel exercises on flat ground, Repetition of previous technical skills (handstand and rolls),	Parallel bar hoist walking/Leg raise on cheese mat/Reverse leg raise on cheese mat/Assisted arm pull up bar/Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	4x5
11-12	Front handspring: Assisted/unassisted shoulder thrust exercises with high-frame hands on the ground, Assisted/unassisted shoulder thrust exercises from the trolley grip, Assisted/unassisted Front handspring exercises on flat ground, Repetition of previous technical skills, Repetition of previous technical skills, Repetition of previous technical skills.	Parallel bar hoist walking/Leg raise on cheese mat/Reverse leg raise on cheese mat/Assisted arm pull up bar/Squashed frog/Bridge back from high mat/Eagle leg stretch forward/Double leg jump between mats	5x5

Descriptive data were calculated for all variables, and the Shapiro-Wilk test was used to assess the normality of distributions. A two-way Repeated Measure ANOVA (2×2) was employed to test for interactions and main effects for time (initial vs. final) and group (training vs. control) on the dependent physical performance variables (BAH, SUC, SLJ, SRF and SF). ES was classified as follows: <0.2was defined as trivial; 0.2–0.6 was defined as small; 0.6–1.2 was defined as moderate; 1.2–2.0 was defined as large; >2.0 was defined as very large; and >4.0 was defined as extremely large (Soslu et al. 2022). Statistical analyses were performed in SPSS (SPSS, Version 25.0) and significance was determined at $p<0.05$.

RESULTS

The mean and standard deviation values of the motoric (SLJ, BAH, SUC, SRF, and SF) parameters of the training program, the effect level, and the significance levels of the training are presented in the tables below.

No statistically significant difference was found in the pre-test and post-test values of the control group (Table 2).

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The Experimental Group showed a statistically significant difference in the Sit-Ups in 30 seconds (SUC) and Sit and Reach Flexibility (SRF) values ($p<0.01$, $d=0.95$, $p<0.01$, $d=0.75$, respectively, Table 3). The effect size of the training on SUC and SRF values is moderate. The positive impact it has on flexibility is particularly beneficial for enhancing children's muscle flexibility improvements. While there were variations in some characteristics, these variations did not reach statistical significance.

When examining Table 4, it is apparent that there is a significant difference in Bend Arm Hang (BAH), Sit-Ups in 30 seconds (SUC), Standing Long Jump (SLJ), and Sit and Reach Flexibility (SRF) values, favoring the Experimental Group (EG) ($p<0.02$, $d=0.780$; $p<0.04$, $d=0.614$; $p<0.00$, $d=2.11$; $p<0.00$, $d=2.11$ respectively). The training program has a substantial impact ($d = 2.11$), especially on the SRF value of the EG. The disparity between the Control Group (CG) and the development of a significant motor skill, such as muscle flexibility, is evident and highly relevant when considering the impact of the training. Although the average disparities in other parameters favored the EG, these differences did not reach statistical significance

Table 2
Control group pre-post test height, weight, strength and flexibility averages

Variables	Group	N	Mean/SD	*MD*	*F*	p	*es*
Height (cm)	**CG Pre Test**	24	121.10±4.48	1.35	-0.88	0.38	0.280
	CG Post Test		122.45±5.15				
Weight (kg)	**CG Pre Test**		22.81±2.82	1.04	-1.04	0.30	0.338
	CG Post Test		23.83±3.31				
BMI (kg/m²)	**CG Pre Test**		15.90±2.06	0,22	-0.36	0.76	0.103
	CG Post Test		16.12±2.19				
BAH (sec)	**CG Pre Test**		0.18±0.01	0.57	-1.41	0.17	0.308
	CG Post Test		0.57±1.79				
SUC (number)	**CG Pre Test**		8.70±5.35	1.35	-0.72	0.47	0.230
	CG Post Test		10.05±6.32				
SLJ (cm)	**CG Pre Test**		96.30±7.98	0.00	1.18	0.24	0.374
	CG Post Test		91.05±8.39				
SRF (cm)	**CG Pre Test**		22.50±3.76	0.80	-0.61	0.54	0.194
	CG Post Test		23.30±4.46				
SF (cm)	**CG Pre Test**		20.50±4.27	0.35	-0.23	0.82	0.073
	CG Post Test		20.85±5.31				

*:p<0,05, BMI: Body Mass Index, BAH: Bent Arm Hang, SUC: Sit Ups in 30seconds Cruch, SLJ: Standing Long Jump Test, SRF: Sit and Reach Flexibility Test, Sf: Static Flexibility. MD: Mean differences, *es:* 0.2–0.6 small; 0.6–1.2 moderate; 1.2–2.0 large; >2.0 very large; >4.0 extremely large.

Table 3
Experiment group pre-post test height, weight, strength and flexibility averages

Variables	Group	N	Mean/SD	*MD*	*F*	p	*es*
Height (cm)	**EG Pre Test**	24	114.18±9.98	6.15	-1.40	0.17	0.402
	EG Post Test		120.33±8.16				
Weight (kg)	**EG Pre Test**		22.38±4.09	0.80	-0.70	0.51	0.191
	EG Post Test		23.18±4.26				
BMI (kg/m²)	**EG Pre Test**		15.85±1.59	0,05	-0.96	0,92	0.030
	EG Post Test		15.90±1.69				
BAH (sec)	**EG Pre Test**		2.74±4.63	1.55	-0.95	0.37	0.468
	EG Post Test		4.29±6.50				
SUC (number)	**EG Pre Test**		9.67±4.83	4.29	-2.62	**0.01**	0.945
	EG Post Test		13.96±6.40*				
SLJ (cm)	**EG Pre Test**		106.65±20.60	7.56	-1.19	0.23	0.344
	EG Post Test		114.21±23.25				
SRF (cm)	**EG Pre Test**		29.33±4.51	3.35	-2.59	**0,01**	0.747
	EG Post Test		32.68±4.45*				
SF (cm)	**EG Pre Test**		20.70±9.92	5.34	-1.77	0.82	0.522
	EG Post Test		26.04±10.51				

*:p<0,05, BMI: Body Mass Index, BAH: Bent Arm Hang, SUC: Sit Ups in 30seconds Crunch, SLJ: Standing Long Jump Test, SRF: Sit and Reach Flexibility Test, Sf: Static Flexibility. MD: Mean differences, *es*: 0.2–0.6 small; 0.6–1.2 moderate; 1.2–2.0 large; >2.0 very large; >4.0 extremely large.

Table 4
Experiment and control group post test height, weight, strength and flexibility averages

Variables	Group	N	Mean/SD	*MD*	*F*	p	*es*
Height (cm)	**EG Post Test**	24	120.33±8.16	2.12	-1.00	0.32	0.310
	CG Post Test		122.45±5.16				
weight (kg)	**EG Post Test**		23.17±4.26	0.66	-0.56	0.57	0.173
	CG Post Test		23.83±3.31				
BMI (kg/m²)	**EG Post Test**		15.90±1.69	0,22	-0,40	0,68	0.112
	CG Post Test		16.12±2.19				
BAH (sec)	**EG Post Test**		4.29±6.50	3.72	2.48	**0.02**	0.780
	CG Post Test		0.57±1.79				
SUC (number)	**EG Post Test**		13.96±6.41*	3.91	2.03	**0.04**	0.614
	CG Post Test		10.05±6.32				
SLJ (cm)	**EG Post Test**		114.21±23.25*	23.16	4.22	**0.00**	1.325
	CG Post Test		91.05±8.39				
SRF (cm)	**EG Post Test**		32.69±4.45*	9.39	6.96	**0.00**	2.110
	CG Post Test		23.30±4.46				
SF (cm)	**EG Post Test**		26.04±10.51	5.19	2.00	0.52	0.623
	CG Post Test		20.85±5.31				

*:p<0,05, BMI: Body Mass Index, BAH: Bent Arm Hang, SUC: Sit Ups in 30seconds Cruch, SLJ: Standing Long Jump Test, SRF: Sit and Reach Flexibility Test, Sf: Static Flexibility. MD: Mean differences, *es*: 0.2–0.6 small; 0.6–1.2 moderate; 1.2–2.0 large; >2.0 very large; >4.0 extremely large.

DISCUSSION

The study aimed to assess the extent to which a 12-week training program, implemented among athletes new to gymnastics, influences their motor characteristics, specifically strength and flexibility. It's acknowledged that children undergoing growth and development experience improvements in anthropometric and motor characteristics even without engaging in sports (Alves and Alves, 2019). Hence, analyzing the performance of children not participating in sports within the same age range is crucial in our study to emphasize the impact level of the training program applied to children experiencing similar growth effects.

Several studies indicate that training enhances technical capacities and contributes to improved scores (Arkayev et al., 2004; Kochanowicz et al., 2009; Clowes and Knowlesvol, 2013; Čeklić et al., 2022). Upon analyzing the Bend Arm Hang (BAH), Sit-Ups in 30 seconds (SUC), Standing Long Jump (SLJ), Sit and Reach Flexibility (SRF), and static flexibility (SF) values measured in the study, the post-test values of the experimental group demonstrated a statistically significant difference compared to the control group, indicating a significantly positive effect of the applied training program.

The significance of flexibility for coordinating movements is evident, and various studies have emphasized the importance of developing flexibility (Ivanov and Bardina, 2021; Holoviichuk et al., 2022). Previous research indicates that beginners, after only a short period of training, demonstrate greater variability in their progress through functional stages compared to experts (Busquets et al., 2011; Williams et al., 2015). Roth et al. suggested that motor skill performance in preschool children can be enhanced with an appropriate training program for boys and girls aged between 4 to 5 years (Roth et al., 2010). The preschool period is considered an ideal age for the development of basic movement skills, including those in gymnastics (Krneta et al., 2015).

According to the study, the mean flexibility of various muscle groups was found to be higher in children during the post-test compared to the pre-test ($p<0.05$). However, children exhibited the lowest levels of flexibility in certain muscle groups after completing a 6-week gymnastics training program, with these differences being statistically significant compared to pre-training levels (Das et al., 2018). Incorporating a static stretching exercise regimen alongside specific training durations led to improvements in flexibility across different muscle groups in children. Static stretching is commonly used in gymnastics training and conditioning programs to enhance joint mobility and overall flexibility, crucial for executing gymnastics routines. Stretching exercises are simple and effective techniques for maintaining flexibility while reducing the risk of injuries (Worrell et al., 1994).

Gymnasts typically commence training in early childhood, with specialization occurring soon afterward. The nature of acrobatic skills necessitates spine mobility, with serious stretching often beginning as early as 4 or 5 years old. Research specifically addressing flexibility in young children (i.e., 4–11 years) is limited, although literature on this topic is increasing. Exercises that develop children into backbend positions emphasizing hyperextension of the thoracic spine and shoulder hyperflexion are commonly used in gymnastics training to improve flexibility.

Notable developments in flexibility were observed in the experimental group in our study, aligning with the findings in existing literature regarding Sit and Reach Flexibility (SF) results.

Numerous studies, reviews, and meta-analyses have documented that pre-adolescents possess the capacity to enhance muscle strength through physical resistance exercise (Behringer et al., 2010; Chaouachi et al., 2014; Granacher et al., 2016). Studies demonstrate that after 6–8 weeks of resistance training, muscle strength can increase by 30–40%. Artistic gymnastics (AG) is a multifaceted sport involving technical skills across various events, necessitating repetitive and prolonged training in fundamental elements and basic positions. This demands coordination and the development of muscle strength, power, endurance, and a broad range of motion, particularly for executing uncommon positions seen in AG events.

During the performance of technical movements requiring significant force and static holds, the development of arm, abdomen, and hip flexor muscle strength is crucial. The experimental group likely experienced a positive increase in Sit-Ups in 30 seconds (SUC) and Bend Arm Hang (BAH) values due to enhanced arm, abdomen, hip flexor, and leg muscle strength from training. Long-term gymnastics training has been associated with increased torque of knee extensors but not knee flexors in prepubertal boys, consistent with our findings (Basa et al., 2002). Cross-sectional studies have also shown that long-term exercise loading induces muscle hypertrophy in trunk and upper extremity muscles in preadolescent athletes (Daly et al., 2004; Sanchis-Moysi et al., 2017).

Our study revealed a positive increase in Standing Long Jump (SLJ) values as a result of increased muscle strength from training. Plyometric training during preadolescence is suggested to be more beneficial for developing jumping performance compared to adolescence, indicating higher potential for improvements in muscle-tendon interaction during preadolescence (Moran et al., 2017). Long-term artistic gymnastics training during preadolescence is associated with increased muscle strength and jumping performance, with athletes benefiting more from muscle strength for improved jumping performance (Pentidis et al., 2020).

It's important to note that muscle strength can be influenced by body size, and children in the Control Group (CG) were taller and heavier. Individuals with higher body mass typically exhibit greater absolute strength. However, our study revealed that relative muscle strength was higher in children with lower body masses. Additionally, the increase in body weight in the control group negatively impacted their anthropometric structure.

Despite its contributions, this study has several limitations. Firstly, we did not track the children's daily unorganized activities and movements/inactivity, which could potentially influence their mastery of motor skills and skill development. Additionally, the number of participants in the study was relatively small, which may limit the generalizability of the findings. However, given the scarcity of information on the effectiveness of developmental gymnastics programs for varying skill levels and optimal motor characteristic development in children, this study and its results remain critical in filling this gap in the literature.

CONCLUSION

In conclusion, there was a significant improvement in the strength and flexibility characteristics of the children in the experimental group compared to the control group. The training program also played a significant role in fostering the development of coordinated movements in children. Specifically, the experimental group exhibited enhancements in explosive power and upper extremity movement speed. While natural growth in the control group positively influenced motor development, its impact was not as pronounced as that of the structured training program. This underscores the importance of organized exercise programs in promoting motor development. Consequently, the effectiveness of preparatory programs on developmental levels will be crucial in shaping trainers' expectations and enhancing the performance development of children in gymnastics.

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VITAL CAPACITY OF THE LUNGS OF TRAMPOLINE GYMNASTS AGED 10-13

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Abstract

Vital capacity (VC) tests are an important tool in assessing the functioning of the respiratory system. Low levels of vital capacity can indicate health problems such as asthma, chronic obstructive pulmonary disease, and other respiratory conditions. The volume of VC depends on many factors, especially the strength of the respiratory muscles, body and chest structure, lung and chest compliance, airway patency, gender, environmental factors, and physical activity. The aim of this study is to determine the level of vital capacity (VC) in girls and boys aged 10-13 who practice trampoline jumping, and to compare the results with reference values for a given gender and age category. The research was conducted among 100 trampoline jumpers (including 57 girls and 43 boys) aged 10-13. As part of the research, spirometric measurement was performed using the portable EasyOne model 2001 spirometer. The obtained results were then compared to reference values calculated on the basis of a study by the European Respiratory Society. The average level of vital capacity in the girls aged 10 was 2.2 liters, in 11-year-olds - 2.45 l, in 12-year-olds 2.54 l, and in 13-year-olds it was 3.02 l. The average level of vital capacity of the examined boys aged 10 was 2.36 l, in 11-year-olds 2.56 l, in 12-year-olds 2.89 l, and in 13-year-olds 3.33 l. These research results indicate that trampoline jumpers show a VC value within the reference values (between the LLN and ULN values). The girls stand out with higher percentage of predicted values for VC at the age of 11 (95.26%) and 13 (100.34%), in comparison with boys at the age of 10 (96.38%) and 12 (96.23%).

Keywords: *trampoline gymnastics, spirometry, vital capacity.*

INTRODUCTION

Spirometry is a method of functional examination of the respiratory system. The test enables measurement and recording of volumes and static capacities such as: tidal volume (TV), inspiratory reserve volume (IRV), expiratory reserve volume (ERV), inspiratory volume (IC) and vital capacity (VC), i.e., the largest change in lung capacity as measured between maximum inhalation and maximum exhalation (VC= TV+IRV+ERV) (Neder et al., 1999; Miller et al., 2005). Vital capacity constitutes the sum of the respiratory volume, including inspiratory and expiratory reserve volume. It ranges from 2.5 to 6.7 liters in men and from 1.2 to 4.6 liters in women (Gutkowski & Konturek 2018). The volume of VC depends on many factors, especially the strength of

the respiratory muscles, body and chest structure, lung and chest compliance, airway patency, gender, environmental factors, and physical activity. (Neder et al., 1999; Gutkowski & Konturek 2018).

Vital capacity tests are an important tool in assessing the functioning of the respiratory system. Low levels of vital lung capacity may indicate health problems such as asthma, chronic obstructive pulmonary disease, and other respiratory conditions (Pellegrino et al., 2005; Quanjer et al., 2012; Gutkowski & Konturek, 2018). Research suggests that vital capacity is also an important tool in assessing the health and physical performance of children and adolescents. Monitoring vital capacity can assist in early detection of respiratory health issues (Beydon et al., 2007; Graham et al., 2019).

In the context of sports, vital capacity is an important indicator of physical performance. In endurance disciplines, the development of aerobic capacity is particularly important, and depends primarily on the efficiency of the circulatory and respiratory systems. The constant development of aerobic capacity is measured using VO2 max and results from the simultaneous improvement of the functioning of these systems in the development period (Wojciechowska-Maszkowska et al., 2005). In addition to determining the oxygen max (VO2 max) to assess the efficiency of the respiratory system, a parameter such as vital capacity of the lungs (VC) can be used. While VC is a static value, it can provide an assessment of the functional capabilities of the respiratory system to some extent (Wojciechowska-Maszkowska et al., 2005).

In trampoline jumping, top competitors perform very complex stunts, including double and triple somersaults with additional turns in the transverse plane ("twists") - all performed in mid-air, at heights approximately 5-6 meters after bouncing from an elastic surface measuring 426x213 cm (Kosendiak et al., 2013). Success in this sport hinges on high physical fitness, optimal body structure, and specific physiological features (Mohammed & Joshi, 2015; Seredyński & Polak, 2015). Assessing the functions of athletes' respiratory and circulatory systems enables the identification of physiological readiness to execute complex meneouvers, thereby maximizing the utilization of athletes' technical skills. (Mohammed & Joshi, 2015). Monitoring parameters such as pulse, blood pressure, respiratory rate, and vital capacity during trampoline jumping training aids in optimizing the training process and selecting appropriate training loads, ultimately contributing to the athletes' skill development. (Mohammed & Joshi 2015).

In order to accurately evaluate the results of vital capacity testing in young athletes, it is important to consider reference values and standards for a given age group and gender. Such standards define the expected value of vital capacity at a given age and gender, which allows for comparison of the test results with the appropriate expected value (Quanjer, et al., 2012). In this way, potential problems with the functioning of the respiratory system can be detected and the progress of sports training can be monitored on an ongoing basis.

The aim of this study is to determine the level of vital capacity in girls and boys aged 10-13 who practice trampoline jumping and to compare the results with reference values for a given gender and age category. The findings from this research can serve professionals specializing in youth trampoline training by aiding in athlete

health diagnosis and designing sports training tailored to the specific needs of the age group and gender

METHODS

The research was conducted in June 2018 during the Polish Junior Championships in Acrobatic Gymnastics, Trampoline Gymnastics and Tumbling. It involved a total of 100 trampoline jumpers (57 girls and 43 boys) aged 10-13 who. These athletes, classified by the Polish Gymnastics Association as sports class III and II, represented 12 clubs from across Poland.

On average, the examined girls participated in 4.9 training sessions per week, each lasting approximately 2.1 hours. Conversely, boys averaged 5.5 training sessions per week, with each session lasting about 1.9 hours.

To assess the vital capacity (VC) of the athletes, spirometry tests were conducted using the portable EasyOne Model 2001 spirometer. Testing took place on the day of the competition, in the morning before training, while the athletes were at rest and in an upright position. Each athlete underwent the test twice, and the better result was used for analysis according to the adopted procedure.

Written consent for participation in the research was obtained from the athletes' parents or legal guardians, club coaches, and competition organizers.

The research protocol was approved by the Bioethics Committee at the Regional Medical Council in Zielona Góra (Bioethics Committee Resolution No.17/82/2017 of 17th July 2017).

Following data collection, statistical analysis was conducted. Arithmetic means Table 1 (M), standard deviations (SD), and ranges of variability (Min-Max) were calculated for vital capacity across the respective age classes (10, 11, 12, and 13) of the tested athletes (Arska-Kotlińska et al., 2002).

The obtained results were compared to reference values derived from studies conducted by the European Respiratory Society and the Global Lung Function Initiative calculators for Spirometry, TLCO, and Lung volume, utilizing prediction equations (Hall et al., 2021):

Female:

VC=exp(−9.230600–0.005517*age+2.116822*log(height)+Mspline)

Male

VC=exp(−10.134371–0.003532*age+2.307980*log(height)+Mspline)

Utilizing the individual body height values of the tested athletes and referencing the study by the European Respiratory Society (Hall et al., 2021) and the Global Lung Function Initiative calculators for Spirometry, TLCO, and Lung volume (http://gli-calculator.ersnet.org/), the Lower Limit of Normal (LLN) and Upper Limit of Normal (ULN) were determined for vital capacity (VC) within the respective age classes of the athletes.

RESULTS

On average, surveyed girls aged 10 have a higher weight than boys of the same age, while at ages 11, 12, and 13, boys tend to be heavier than girls. Regarding body height, girls aged 10 and 12 are, on average, taller than their male counterparts, whereas boys aged 11 and 13 are taller than girls. Both girls' and boys' height and weight increase with age.

Numerical values for body height, body weight and BMI of the examined girls and boys

Feature	Age	Girls					Boys				
		n	M	SD	Min	Max	n	M	SD	Min	Max
Body mass [kg]	10	13	32.38	3.74	27	40.70	8	31.36	3.14	25.70	36.10
	11	18	33.38	5.01	23.10	42.20	9	35.41	4.79	28.40	43.80
	12	20	36.03	5.24	29.50	45.90	19	37.38	5.81	28.60	53.00
	13	18	43.87	6.75	34.90	59.00	11	45.24	7.46	32.40	61.40
Body height [cm]	10	13	139.77	3.31	134.00	144.00	8	137.13	4.23	128.00	142.00
	11	18	143.22	7.41	134.00	159.00	9	144.33	5.10	136.00	153.00
	12	20	148.05	5.69	141.00	162.00	19	147.05	6.71	137.00	160.00
	13	18	154.22	6.07	140.00	162.00	11	156.82	8.16	145.00	176.00
BMI	10	13	16.56	1.63	13.69	19.63	8	16.64	0.98	15.03	18.11
	11	18	16.19	1.44	12.86	17.87	9	16.92	1.34	14.08	18.71
	12	20	16.37	1.65	14.13	19.63	19	17.18	1.40	14.64	20.70
	13	18	18.34	1.78	15.41	22.48	11	18.31	1.90	13.31	18.31

Table 2:
Vital capacity VC [l] of examined trampoline gymnasts broken down by age

Age	Girls					Boys				
	n	M	SD	Min	Max	n	M	SD	Min	Max
10	13	2.20	0.27	1.68	2.60	8	2.36	0.33	1.87	2.82
11	18	2.43	0.26	1.91	2.88	9	2.57	0.22	2.32	2.98
12	20	2.51	0.35	1.87	3.19	19	2.86	0.32	2.37	3.47
13	18	3.07	0.39	2.24	3.84	11	3.28	0.51	2.60	4.24

The average BMI values for girls in each age group indicate normal body weight. However, cases of grade I underweight were observed among 10- and 13-year-old girls, and grade II underweight among 11- and 12-year-olds. Similarly, the average BMI for boys in each age group also suggests normal body weight. Instances of underweight class I were noted among 11- and 12-year-old boys, with cases of underweight class II recorded among the oldest group (13-year-olds).

In each age category, the examined boys exhibit, on average, higher vital capacity compared to their female counterparts practicing the same sports discipline. Vital capacity (VC) increases with the age of the respondents, both for girls and boys.

The graphical representation of the average (M) vital capacity of the tested athletes aged 10-13 who practice trampoline jumping is presented in Figure 1.

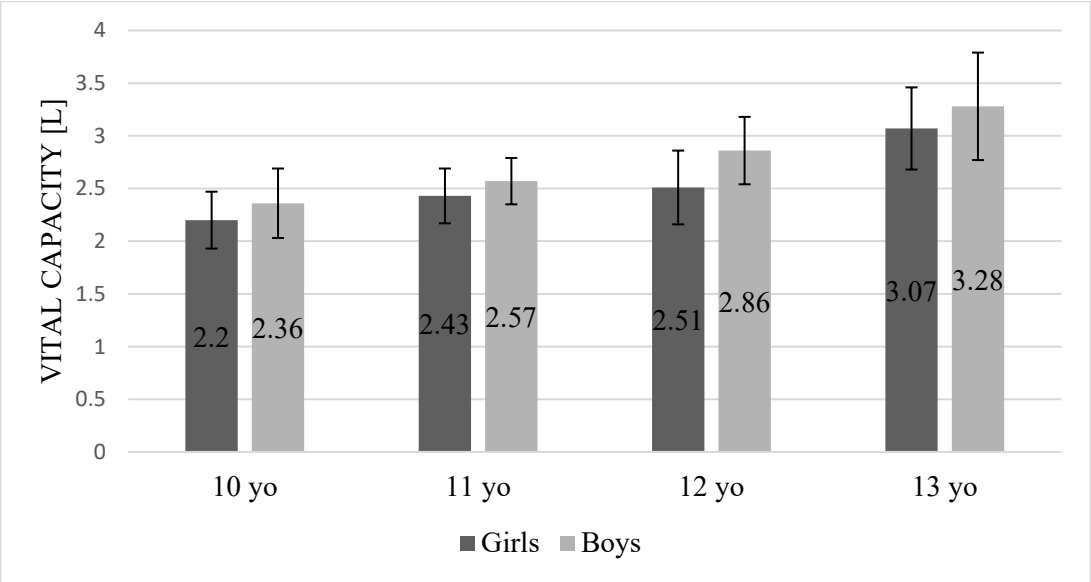

Figure 1. *Graphical representation of average vital capacity of the lungs of examined girls and boys with standard deviation*

Table 3
Vital capacity of the lungs of tested female athletes in relation to predicted values

Age	n	VC	Predicted	LLN	ULN	% Predicted
10	13	2.20 ± 0.27	2.39	1.95	2.83	91.97
11	18	2.43 ± 0.26	2.55	2.08	3.02	95.26
12	20	2.51 ± 0.35	2.77	2.26	3.28	90.54
13	18	3.07 ± 0.39	3.06	2.49	3.63	100.34

Table 4
Vital capacity of the lungs of the tested male athletes in relation to predicted values

Age	n	VC	Predicted	LLN	ULN	% Predicted
10	8	2.36 ± 0.33	2.45	1.98	2.94	96.38
11	9	2.57 ± 0.22	2.81	2.26	3.36	91.59
12	19	2.86 ± 0.32	2.97	2.40	3.56	96.23
13	11	3.28 ± 0.51	3.50	2.82	4.20	93.72

Based on the average body height values of the tested female athletes, as specified in the study by the European Respiratory Society (Hall et al. 2021) and the Global Lung Function Initiative calculators for Spirometry, TLCO and Lung volume (http://gli-calculator.ersnet.org/), the presented results indicate that the tested 10-year-old athletes achieve 91.97% of the predicted values, 11-year-olds achieve 95.26% of the predicted values, 12-year-olds achieve 90.54%, and 13-year-olds achieve 100.34% (Table 3). In all age categories, the average vital capacity of the tested athletes

is within the reference values (between LLN and ULN) (Table 3).

The presented results indicate that the tested 10-year-old athletes achieve 96.38% of the predicted values, the 11-year-olds 91.59% of the predicted values, the 12-year-olds 96.23%, and the 13-year-olds 93.72%. In all age categories, the average vital capacity of the tested athletes is within the reference values (between LLN and ULN values) (Table 4).

In terms of average values, both the tested male and female athletes exceeded 90% of the predicted values for VC (Figure 2). The girls stand out with higher % predicted values for VC at the ages of 11 (95.26%) and 13 (100.34%), while the boys excel at the ages of 10 (96.38%) and 12 (96.23%).

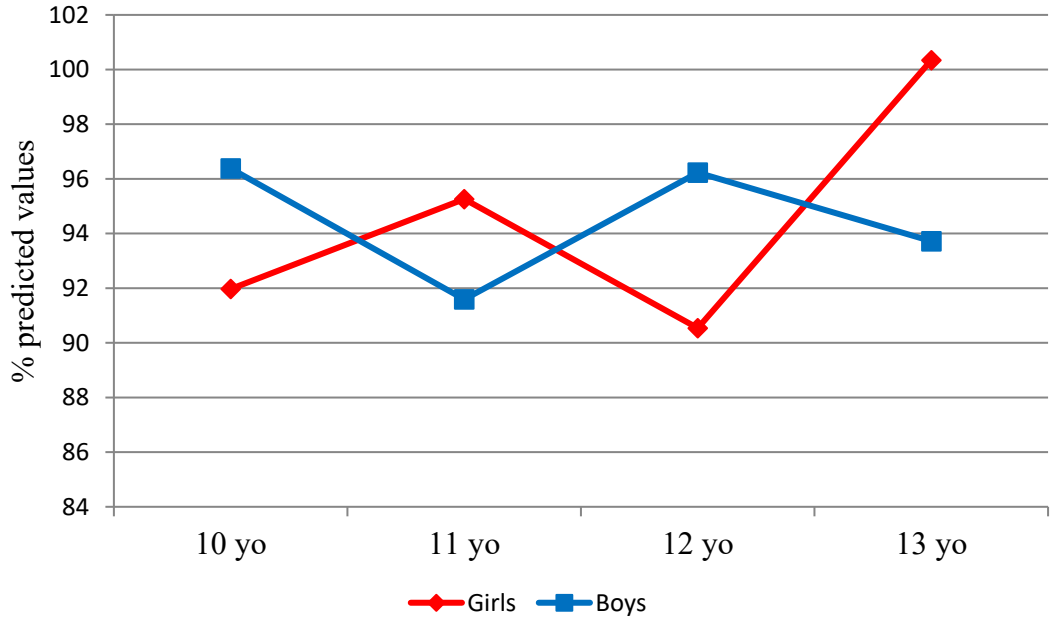

Figure 2. *The graphical representation of the achieved % predicted values for VC of the tested athletes*

DISCUSSION

Trampoline jumping is a technical discipline that naturally requires specific physical predispositions such as strength, power, motor coordination, speed, and stamina. While not categorized as an endurance discipline due to the nature and duration of the exercise, trampoline sports demand adaptation of the respiratory system to the effort exerted. A typical trampoline routine lasts approximately 30-60 seconds, including preparatory jumps. This necessitates an efficient respiratory system, as athletes must inhale and exhale at precise moments or hold their breath when necessary, all while executing complex stunts. Research by Hes & Asienkiewicz (2020) has demonstrated that children aged 7-9 who engage in sports acrobatics and trampoline jumping generally exhibit superior physical fitness compared to non-training peers, except in hand grip strength. However, they typically excel particularly in flexibility (Seredyński & Polak, 2015), which indirectly relates to lung capacity.

Observations from spirometric examinations of trampoline athletes indicate

that, on average, boys in each age category exhibit higher vital capacity compared to their female counterparts in the same sports discipline. Research by Todorov (1982) highlights gender differences in vital capacity, with men generally demonstrating higher values."

The tested female athletes achieve predicted values of VC ranging from above 90% to 100.34%, with results ranging from 90.54% for 12-year-olds to 100.34% for 13-year-olds. Similarly, the tested athletes, on average, achieve predicted values of VC above 90%, albeit with a slightly narrower range, from 91.59% for 11-year-olds to 96.38% for 10-year-olds..

These findings indicate that while trampoline jumping competitors maintain VC values within the reference range (between LLN and ULN values - see Table 3.4), they do not consistently reach 100% of the predicted VC values, except for girls aged 13.

These results align with existing literature, underscoring the role of sports training in shaping lung function, a phenomenon influenced by the nature of the sport practiced. The adaptation of the cardiovascular and respiratory systems to various types of sports training and the reversibility of this process following the cessation of training in adults is a well-known phenomenon (Amann, 2012). It is well-established that physical training enhances lung function parameters, including vital capacity of the lungs (VC) (Durmic, 2017). Additionally, individuals actively engaged in sports exhibit higher VC compared to sedentary individuals (Tulin et al., 2012). Studies have consistently shown increased lung functional parameters in athletes compared to sedentary controls (Miller et al., 2005; Guenette et al., 2007, Myrianthefs et al., 2014). Research by Mazic et al. (2015) demonstrated that basketball players, water polo contestants and rowers, exhibited statistically higher vital capacity (VC), forced vital capacity (FVC), and forced expiratory volume in one second (FEV1) compared to healthy sedentary individuals.

Research on vital lung capacity among athletes in technical sports, including gymnastic disciplines, is limited. However, Zhao et al. (2019) conducted a study analyzing VC among athletes in various sports, including basketball, judo, fencing, swimming, table tennis, and volleyball, with participants under the age of 15. The study revealed that table tennis players exhibited significantly lower vital lung capacity compared to athletes in other sports examined in the study.

Research conducted among children and adolescents consistently demonstrates higher vital lung capacity (VC) values in individuals engaged in various sports disciplines compared to those who lead sedentary lifestyles. Kurkcu & Gokhan (2011) observed that 10-13-year-old handball players exhibited higher VC compared to non-sporting peers. Similarly, Nikolic & Ilic (1992) found that athlete students, with an average age of 15 years, had slightly higher VC values than non-athletes (4.9 and 4.57 l, respectively). reported higher VC and forced vital capacity (FVC) values, along with lower resting heart rate and blood pressure, in schoolchildren engaging in sports compared to sedentary students. This suggests that physical training strengthens respiratory muscles. Additionally, research by Sharma (2023) indicates that 8 weeks of speed and agility training (SAQ) in school-age children (13-17 years old) enhances VC. Ramesh & Venkatachalapathy (2022) demonstrated significant improvements in respiratory

indicators, including vital capacity, following strength and endurance training. Similar findings were reported by Velmurugan (2019) and Dinesh et al. (2020) after strength and circuit training. Furthermore, Khosravi et al. (2013) concluded that endurance training leads to a significant increase in vital capacity.

It is worth contemplating why the examined trampoline athletes did not achieve vital capacity levels above 100% of predicted values despite their considerable training efforts. This raises questions about the nature of the athletes' training regimen, which primarily focuses on refining technique and mastering new maneuvers. While motor preparation, including endurance and strength training, is also integral, its intensity may not be sufficient to elicit significant physiological adaptations in young athletes. Therefore, future studies should delve into the relationship between lung vital capacity and trampoline performance. Additionally, attention should be given to the balance between strength and endurance exercises in training and their role in shaping respiratory function in young trampolinists.

According to the Global Lung Function methodology, body height serves as a primary determinant when calculating predicted VC values, as it is closely associated with lung capacity. However, numerous studies suggest correlations between vital capacity and other somatic characteristics and indicators, such as body weight, chest volume, and BMI (Pavlica et al., 2010; Durmic et al., 2015).

Male and female trampoline jumpers typically exhibit a slim body structure, low body weight, and low BMI. This observation is supported by research conducted by Hes & Asienkiewicz (2020) among children aged 7-9, as well as by Seredyński & Polak (2018) among girls aged 11-12, and by Hes and Nowacka-Chiari (2019), which assessed BMI index according to the classification by Cole et al. (2000, 2007) among girls and boys aged 11-13 engaged in trampolining.

The low values of body height and body mass observed among the studied female and male athletes are further supported by reference to centile grids of the Polish population. In each age category, both among girls and boys, these somatic traits fall below the 50th percentile (Kułaga et al., 2015). Specifically, the lowest values relative to the Polish population for body height were recorded among girls and boys aged 12 years (between the 25th and 10th percentile), while for body mass, the lowest values (between the 10th and 25th percentile) were observed among girls aged 11 and 12 and boys aged 12.

The slim body build, low body weight, and low BMI of the examined individuals may influence their vital capacity. Therefore, exploring the relationships between lung function parameters and various somatic features among gymnastic athletes warrants further investigation.

CONCLUSIONS

In each age category, the studied boys exhibit, on average, higher vital capacity compared to their female counterparts. The average vital capacity levels for girls aged 10, 11, 12, and 13 were 2.2 liters, 2.45 l, 2.54 l, and 3.02 l, respectively. Meanwhile, the average vital capacity levels for boys aged 10, 11, 12, and 13 were 2.36 liters, 2.56 l, 2.89 l, and 3.33 l, respectively.

These research findings indicate that trampoline jumpers achieve vital capacity values within the reference range (between LLN and ULN values). Notably, girls demonstrate higher % predicted values for

VC at the ages of 11 years (95.26%) and 13 years (100.34%), while boys excel at the ages of 10 years (96.38%) and 12 years (96.23%).

The failure of respondents to achieve 100% predicted values for VC (except for girls aged 13), despite significant training volumes, may be attributed to their slim body structure, low body mass, and low BMI. Therefore, exploring the relationships between lung function parameters and various somatic features among gymnastic athletes warrants consideration.

LIMITATIONS

This study is subject to several limitations that may impact the representativeness and interpretation of the results. Firstly, the small number of participants in each age category may limit the generalizability of the findings. Moreover, the diverse sports levels among athletes within the analyzed age categories introduce additional variables that could potentially interfere with result interpretation.

Furthermore, it is important to acknowledge that the sports level of trampoline jumpers in Poland may not be as high compared to European and global standards. This discrepancy could impact the overall lung function outcomes observed in the study.

Given these limitations, there is a need for further research incorporating a more detailed analysis of lung functions among gymnastics athletes. This analysis should consider various somatic features that may influence lung function outcomes, thereby providing a more comprehensive understanding of respiratory health in this population

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INVESTIGATION IN TERMS OF SOME VARIABLES OF THE POSITIONAL CORRELATION OF THE STRAIGHT-ARM PRESS HANDSTAND MOVEMENT IN ARTISTIC GYMNASTS

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Abstract

The objective of this study was to investigate in terms of some variables the positional correlation of the press to handstand with eyes open and eyes closed in the right-left sagittal planes in artistic gymnasts. Correlation analysis was conducted to evaluate the data. According to the findings obtained from analysis in the right and left planes at 0°, a statistically significant correlation was observed both in the negative and positive direction. The analysis of the gymnasts' press to handstand with eyes open and eyes closed, as measured in the right and left planes at 90°, revealed a statistically significant correlation both in the negative and positive direction. Likewise, the analysis of the gymnasts' press to handstand with eyes open and eyes closed, as measured in the right and left planes at 180°, revealed a statistically significant correlation both in the negative and positive direction. We found in our study that the wider the triangle formed by the gymnasts' shoulders, hips, and feet in the starting position of the press to handstand with eyes open was indicative of a poor starting technique, that at 90° the gymnasts' proprioception functioned differently in the right and left planes when performing a handstand with eyes open and eyes closed, and that at 180° the central nervous system may play an important role for the arm muscles in the right plane in maintaining the desired balance in the absence of visual input when performing the handstand with eyes closed.

Keywords: *handstand, gymnastic, plane, position, proprioception.*

INTRODUCTION

Gymnastics is a multidisciplinary sports branch that encompasses a wide array of performance variables, requiring a combination of speed, strength, endurance, flexibility, agility, and psychological traits such as courage and quick decision-making (Şentürk & Sezen, 1999; Çoknaz, Yıldırım & Özengin, 2008). Artistic gymnastics, in particular, places a significant emphasis on intensive use of the upper extremities, as gymnasts strive to execute acrobatic

movements seamlessly and fluidly (Pala & Avcı, 2016).

Postural balance is paramount for success in artistic gymnastics, especially during sequences of moves. Gymnasts undergo drills to enhance and refine their movement skills, particularly for maneuvers requiring precise postural control, such as the handstand (Şimşek & Ertan, 2011). The handstand, characterized by supporting the body in a stable, inverted vertical position on the hands (Wyatt, Vicinanza, Newell, Irwin, & Williams, 2021), is a fundamental technique in artistic gymnastics. Improper execution of the handstand can expose gymnasts to various risks, including injury and failure to meet performance expectations in training sessions or competitions. Achieving the correct angles and coordinates in a handstand offers numerous advantages to gymnasts, enabling them to execute moves with proper technique and reducing the risk of injury. Multiple joints (wrist, shoulder, arm, head, leg-ankle, hip joints) and muscles (trapezius, biceps/triceps brachii, deltoid, rectus femoris, etc.) play crucial roles in maintaining balance and coordinating positioning during handstands.

An essential factor that helps gymnasts maintaining their desired handstand position is the sense of proprioception, which integrates visual, auditory, neural, and muscular cues. Proprioception involves the body's ability to sense its position and movement in space, updating visual and vestibular signals during motion. Mechanoreceptors in tendons, muscles, and ligaments play a crucial role in this process (Riemann & Lephart, 2002; Kaynak, Altun, Özer & Akseki, 2015). While mechanoreceptors interpret signals from visual sensors to consciously maintain balance during a handstand, visual sensors may have a more specific role in unconscious reactions during movement, suggesting the importance of visual processes in achieving and sustaining balance. Proprioception engages both unconscious and conscious reactions to motion (Yılmaz & Gök, 2006). Therefore, our study aimed to investigate how performing the handstand with eyes open and eyes closed affects gymnasts' motion mechanism.

We believe that understanding the positional correlation of the press to handstand, one of the fundamental movements in artistic gymnastics, is crucial for a successful sports career. Our study seeks to contribute valuable insights into teaching proper positioning for the handstand.

METHODS

We conducted extensive research using search engines such as NCBI (including Pubmed and Pubmed Central), Researchgate, Google Scholar, and Web of Science, which are registered in internet databases, to inform our study. During these searches, we evaluated data obtained by using keywords such as "artistic gymnastics," "gymnastics and handstand," "handstand and balance," and "proprioception and balance in gymnastics." We used them to supplement our study findings.

The inclusion and exclusion criteria for the research group are provided in Table 1, Demographic data of the research group are provided in Table 2.

Table 1
Criteria for athlete participation in the study: inclusion and exclusion

Inclusion criteria	Exclusion criteria
Being under 18 years old	Being an artistic gymnastics athlete
Being Turkish Citizen	Being able to communicate in Turkish
Being a male and female athlete	Have parental consent forms
Not having any disability	Being an elite athlete
Not having any disease that can affect the balance	Being an international athlete
Not having an infectious disease	Being an international and national level competitor

Table 2
Demographic data of the participating gymnasts (n=20).

Variables	Mean	SD
Age (years)	16.85	2.28
Height (cm)	1.64	9.73
Weight (kg)	57.57	9.49
BMI (kg/m^2)	21.21	1.85
Sports years (years)	10.85	2.41
Daily training hours (hours)	4.52	1.12
Warm-up time (minutes)	34.76	8.72

SD: Standard deviation

The study included 16 male and 5 female gymnasts, all members of the Murat Canbas Training Centre in Bolu, with prior experience in national and international competitions. Participation in the study was voluntary, and athletes did not inhibit their involvement. Written parental consent was obtained for participants under the age of 18.

Given that the participating athletes are also engaged in educational activities, our tests were designed not to disrupt their academic programs. Additionally, precautions were taken to assess whether athletes exhibited any symptoms of illness, including those related to seasonal conditions and the COVID-19 virus.

Table 2 represents the anthropometric measurements of the gymnasts, including age, height, weight, and BMI, were recorded at least twice by the tester, and the mean values were documented on personal information forms.

The height of the athletes in our study was measured with a Holtain brand device that was made with a height ± sensitivity of 1mm. Weight measurements were taken with the Xiaomi Mi Body Composition Scale 2 Model, which has a precision of ± 50 g. Body mass index (BMI) values were calculated by dividing the weight by the square of height.

Upon examining the demographic information of the athletes in the artistic gymnastics branch:

- It was observed that the gymnasts had a sports history of over ten years.
- They trained for an average of four hours per day, with training sessions starting with warm-up exercises lasting at least half an hour.

To assess the force exerted by gymnasts during the straight-arm press to handstand, the arm force utilized to shift the load from lower extremities to shoulders, abdomen, scapula, and back muscles through core strength was measured using a Lafayette dynamometer. This measurement was conducted with the gymnasts seated on a flat surface. Prior to measurement, gymnasts performed specialized warm-up exercises targeting the shoulders, abdomen, scapula, and back muscles.

Subsequently, the dynamometer was positioned on the distal arm section of the gymnasts, who were then instructed to exert maximal force by pushing the dynamometer both backward and forward. Each measurement was repeated at least twice (once for the right and once for the left arm), and the mean value was recorded on the information form by the tester.

The gymnasts' press to handstand with eyes open and closed was analyzed in the right-left planes at three different phases of the handstand: 0°, 90°, and 180°. Two GoPro cameras, capable of 5.3K60/2.7K240 Video and 27MP Photos, were positioned on each side, right and left, at a distance of 3 meters each. Prior to camera measurements, the area designated for the gymnasts' movements was prepared by the tester to ensure proper positioning for camera measurements, as seen on Figure 1.

Figure 1. Exemplary illustration of the calibration frame and camera angle

To assess the gymnasts' movements in a coordinate plane (X, Y), a rectangular calibration frame was established using 1.30 m high slalom poles, defining a 2 m long and 1 m wide area. Green markers were applied to specific anatomical landmarks on the gymnasts' lateral side of the hand, wrist joints, the lateral proximal end of the ulna, the greater tubercle of the humerus, the lateral and lower parts of the latissimus dorsi, the greater trochanter of the femur, the lateral part of the knee joint, and the articular cavities of the ankles.

The gymnasts performed the press to handstand with their eyes open or closed in a randomized order. Upon reaching the handstand position, they were instructed to maintain it for at least 5 seconds. Gymnasts

who failed to execute the press to handstand satisfactorily on their first attempt were given two additional attempts.

After the handstand, the video recordings were analyzed with Kinovea motion analysis software. Two researchers simultaneously paused the videos at predetermined positions for each phase of the motion in two directions and inserted markers.

During marking, the x-y coordinates of the gymnasts' right and left feet were determined in the triangle (0°), feet parallel to the ground (90°), and handstand (180°) positions on the software's coordinate system. Additionally, the coordinates of the height of the feet from the ground, the triangle, and shoulder angles were determined and included in the analysis.

Coordinate, force, and inertial data were integrated into two-dimensional dynamic analyses. Each gymnast was depicted with four segment models: hand, arm, trunk-head, and leg sections. Corresponding joints for these sections were identified as wrist, shoulder, and hip.

Equations of motion were developed for each of the four segments, with three equations assigned to each segment, resulting in a total of twelve equations. Within each of the three joints, six equations were left, which could be resolved to eliminate reactions. These reactions were denoted as T1, T2, T3, and Ø1, Ø2, and Ø3 (Yeadon & Trewartha, 2003) (Figure 2).

The kinematics of handstand balancing, particularly the angle positions of the joints, the center of mass, and the torques due to the force of gravity, are illustrated. Active engagement of the joints and muscles during a handstand can significantly aid athletes in achieving the desired balance. Kerwin and Trewartha (2001) concluded in their study that multiple joints actively contribute to maintaining handstand balance in the anterior-posterior direction. During a handstand, which demands effective production of relative force, athletes must counteract the torque generated by the force of gravity with their body weight.

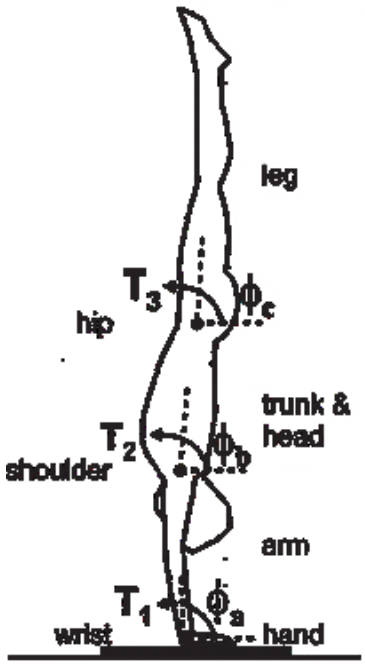

Figure 2. Demonstration of the four segment model in the handstand movement.

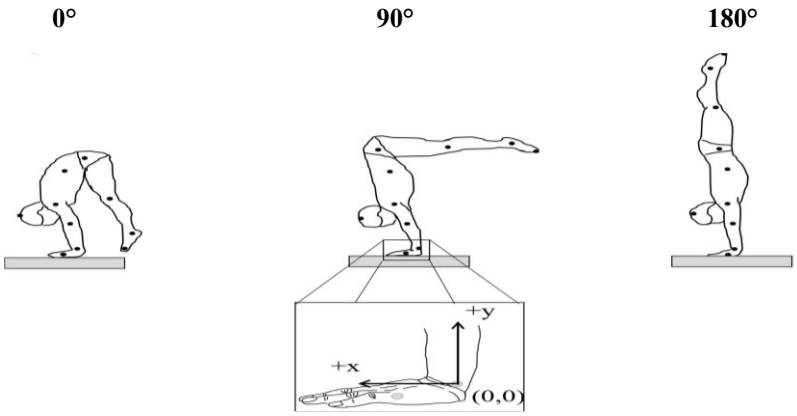

Figure 3. Straight-arm press to handstand measurement positions

The press to handstand position for measurement was standardized for the straight-arm press to handstand (Figure 3). With the assistance of expert coaches from the national team, athletes executed the straight arm press handstand movement on a force surface. Prior to measuring the handstand movement, athletes were instructed to maintain tension in their wrist, elbow, shoulder, hip, knee, and ankle joints throughout the duration of the measurement.

During the movement, athletes positioned their wrist joints to form a 90-degree angle over the x and y axes. Furthermore, athletes were cautioned against stepping forward or backward during the handstand movement to maintain control of pressure and optimize force utilization, especially considering the effect of gravity while in the inverted position.

In this study, the angular positions of the handstand movement performed with eyes open and closed in the sagittal plane were evaluated. The statistical analysis of the data obtained utilized the correlation analysis method, commonly employed to ascertain the direction and strength of relationships between variables. The data were uploaded to the SPSS 22.0 software package for analysis, and the results were interpreted. The statistical significance level for our study data was set at $p < 0.05$.

RESULTS AND DISCUSSION

The data obtained from the study are presented in Table 3, Table 4, Figure 4 and Figure 5. When examining the correlation between locations on the coordinate plane and isometric force values of the gymnasts' body segments at the starting position (0°) with eyes open, in terms of right plane coordinate data, a moderate and negative correlation ($r = -0.455$) was observed between right arm posterior isometric force values and feet X ($p < 0.05$). According to left plane coordinate data, a negative correlation was observed between right arm posterior isometric force values and the location of shoulder angle ($r = -0.453$) and feet X ($r = -0.195$), and a positive correlation was observed with the triangle ($r = 0.532$). In addition, a negative correlation was observed between left arm anterior isometric force values and the location of shoulder angle ($r = -0.354$) and shoulder Y ($r = -0.576$) ($p < 0.05$). A positive correlation was observed between left arm posterior isometric force values and the triangle ($p < 0.05$). According to both coordinate data obtained from the right plane ($r = 0.487$) and

coordinate data from the left plane (r = 0.496), a correlation was observed between shoulder angle and shoulder Y ($p < 0.05$). Regarding both planes, statistically significant correlations were observed between right and left shoulder angle (r = 0.615), triangle (r = 0.760), feet Y (r = 0.868), hip Y (r = 0.863), shoulder X (r = 0.654), and shoulder Y (r = 0.811) ($p < 0.05$).

Table 3.
Isometric strength values of participations.

Variable	Mean	SD
R.A.A.I. (kg)	6.570	1.910
R.A.P.I. (kg)	6.619	1.987
L.A.A.I. (kg)	6.857	2.032
L.A.P.I. (kg)	7.380	1.990

Abbreviations: R.A.A.I: Right Arm Anterior Isometric, **R.A.P.I:** Right Arm Posterior Isometric, **L.A.A.I:** Left Arm Anterior Isometric, **L.A.P.I:** Left Arm Posterior Isometric, **SD:** Standart Deviation

P<0,05

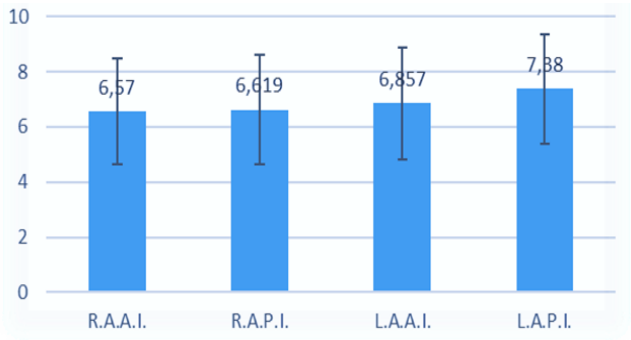

Figure 4. Isometric strength graph of gymnastics (The data in the graph are given in kg)

Table 4
Coordinate values according to participants' position with eyes open and eyes closed.

Variable	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed
H.F.G.	-	-	73.04 ± 12.40	73.33 ± 10.28	178.50± 11.39	179.34± 10.82
H.S.A.	133.12 ± 8.97	135.12 ± 11.27	145.45 ± 10.95	145.41 ± 12.05	159.01 ± 9.00	159.66 ± 9.33
H.S.T.	70.15 ± 12.73	66.86 ± 10.16	91.08 ± 1.95	90.73 ± .80	170.92 ± 7.48	172.02 ± 5.06
F.X.C.	109.90 ± 27.74	105.39 ± 22.36	44.86 ± 15.60	45.07 ± 15.78	41.33 ± 9.51	41.52 ± 10.12
F.Y.C.	113.02 ± 10.94	105.97 ± 24.99	117.30 ± 24.81	116.04 ± 32.47	61.56 ± 15.14	64.90 ± 12.18
H.X.C.	47.33 ± 5.68	44.49 ± 10.86	35.60 ± 6.32	45.20 ± 42.98	30.05 ± 7.24	30.46 ± 6.27
H.Y.C.	81.01 ± 12.64	80.63 ± 10.49	57.21 ± 5.73	56.97 ± 6.67	68.11 ± 5.64	67.66 ± 6.96
S.X.C.	79.01 ± 4.98	77.92 ± 7.18	78.83 ± 9.92	79.21 ± 8.75	77.15 ± 4.76	77.50 ± 5.43
S.Y.C.	56.37 ± 9.52	56.40 ± 7.29	52.00 ± 8.90	51.68 ± 8.79	66.93 ± 5.53	65.72 ± 7.69

Abbreviations: H.F.G: Height of Feet from Ground, **H.S.A:** Handstand Shoulder Angle, **H.S.T:** Handstand Shoulder Triangle, **F.X.C:** Feet X Coordinate, **F.Y.C:** Feet Y Coordinate, **H.X.C:** Hip X Coordinate, **H.Y.C:** Hip Y Coordinate, **S.X.C:** Shoulder X Coordinate, **S.Y.C:** Shoulder Y Coordinate, **Mean ± sd.** = Mean ± standard deviation

P<0,05

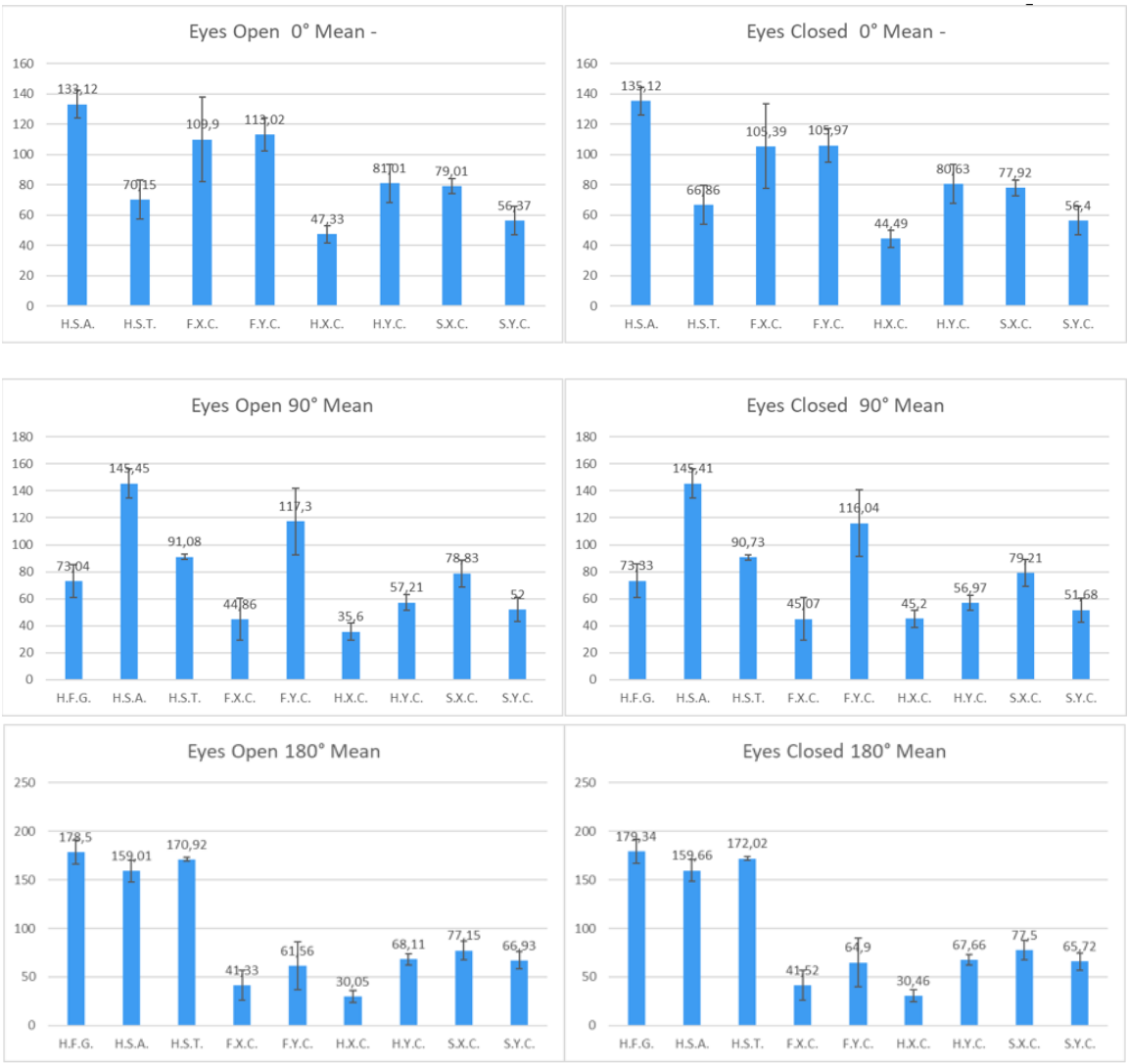

Figure 5. Coordinate position graph of gymnastics

At the starting position (0°) with eyes closed, according to the right plane coordinate data, a moderate and negative correlation was observed between left arm anterior isometric force values and shoulder angle (r = -0.548), as well as between right arm posterior isometric force values and shoulder Y (r = -0.469). In the left plane coordinate data, a negative correlation was found between left arm posterior isometric force values and feet X (r = -0.615) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left shoulder angle (r = 0.833), triangle (r = 0.848), feet Y (r = 0.756), feet X (r = 0.484), hip Y (r = 0.913), and shoulder Y (r = 0.863) ($p < 0.05$).

At 90° with eyes open, in the right plane coordinate data, a moderate correlation was noted between right arm posterior isometric force values and feet Y (r = 0.497) and shoulder Y (r = -0.455). A moderate and negative correlation was observed between left arm posterior isometric force values and shoulder angle (r = -0.455). In the left plane coordinate data, statistically significant correlations were found between right arm anterior isometric force values and shoulder

angle (r = -0.595) and shoulder Y (r = -0.513), between right arm posterior isometric force values and feet Y (r = 0.585) and shoulder Y (r = -0.581), between left arm anterior isometric force values and shoulder angle (r = -0.552) and shoulder Y (r = -0.537), and between left arm posterior isometric force values and shoulder angle (r = -0.546) and feet Y (r = 0.562) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of feet from the ground (r = 0.976), feet X (r = 0.676), feet Y (r = 0.683), hip X (r = 0.469), hip Y (r = 0.774), and shoulder Y (r = 0.880) ($p < 0.05$).

At 90° with eyes closed, according to the right plane coordinate data, a moderate and negative correlation was observed between right arm anterior isometric force values and shoulder Y (r = -0.462). Additionally, a moderate correlation was noted between right arm posterior isometric force values and feet Y (r = 0.554) as well as shoulder Y (r = -0.521). Furthermore, a moderate and negative correlation was seen between left arm posterior isometric force values and shoulder angle (r = -0.461) and shoulder Y (r = -0.515). In the left plane coordinate data, statistically significant correlations were observed between right arm anterior isometric force values and shoulder angle (r = -0.609), as well as between right arm posterior isometric force values and shoulder angle (r = -0.567), feet Y (r = 0.497), and shoulder Y (r = -0.576) ($p < 0.05$). Similarly, statistically significant correlations were seen between left arm anterior isometric force values and shoulder angle (r = -0.608), and between left arm posterior isometric force values and shoulder angle (r = -0.664) and shoulder Y (r = -0.523) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of feet from ground (r = 0.952), shoulder angle (r = 0.582), feet X (r = 0.779), feet Y (r = 0.677), hip Y (r = 0.808), and shoulder Y (r = 0.815) ($p < 0.05$).

At 180° with eyes open, according to the right plane coordinate data, a moderate and positive correlation was observed between right arm posterior isometric force values and height of feet from ground (r = 0.501) and feet X (r = 0.543), while the correlation with hip X (r = -0.636) was moderate and negative. Additionally, a moderate and negative correlation was found between left arm anterior isometric force values and shoulder Y (r = -0.505), as well as between left arm posterior isometric force values and shoulder Y (r = -0.464). In the left plane coordinate data, a moderate and positive correlation was observed between right arm posterior isometric force value and height of feet from ground (r = 0.502). Across both planes, statistically significant correlations were seen between right and left height of feet from ground (r = 0.976), feet X (r = 0.758), feet Y (r = 0.635), hip Y (r = 0.741), and shoulder Y (r = 0.642) ($p < 0.05$).

At 180° with eyes closed, according to the right plane coordinate data, a moderate and significant correlation was observed between right arm anterior isometric force values and shoulder angle (r = -0.445), as well as between right arm posterior isometric force values and height of feet from ground (r = 0.492), shoulder angle (r = -0.514), and hip X (r = -0.558) ($p < 0.05$). Additionally, a moderate and significant correlation was seen between left arm anterior isometric force values and shoulder angle (r = -0.453), and between left arm posterior isometric force values and shoulder angle (r = -0.578) and triangle (r = 0.527) ($p < 0.05$). In the left plane coordinate data, a moderate and positive correlation was observed between right arm posterior

isometric force values and height of feet from ground ($r = 0.514$) ($p < 0.05$). Across both planes, statistically significant correlations were observed between right and left height of feet from ground ($r = 0.967$), shoulder angle ($r = 0.678$), feet X ($r = 0.810$), feet Y ($r = 0.636$), hip Y ($r = 0.795$), and shoulder Y ($r = 0.815$) ($p < 0.05$)..

Our study revealed contrasting findings regarding the relationship between right-left isometric arm muscle force at 0° and coordinate values such as shoulder angle, feet X, and shoulder Y. While there was an increase in right-left isometric arm muscle force at 0°, there was a decrease in coordinate values related to shoulder angle, feet X, and shoulder Y. Additionally, we observed that with an increase in right arm posterior isometric arm muscle force in the left plane with eyes open, the angles of the triangle formed by shoulders, hip, and arms widened, resulting in poorer handstand performance. This phenomenon suggests that gymnasts may shift their body mass center and body pressure center to their posterior right arm during the press to handstand. Notably, this was not observed in the starting position (0°) of the press to handstand with eyes closed.

We found that in the starting position with eyes closed, gymnasts utilized their left arm posterior isometric muscle force in the left plane and their left arm anterior isometric muscle force in the right plane. These results imply that gymnasts may utilize their arm force at 0° more balanced and economical manner when their eyes are closed. Furthermore, our findings suggest that gymnasts develop different proprioception strategies under changing conditions (eyes open/closed) to master the starting position of the press to handstand.

To further explore this phenomenon, Heinen, Jeraj, Vinken, & Velentzas (2012) conducted a study on rotational preferences in gymnastics, revealing that gymnasts develop individual rotational preferences and talent practices. This finding aligns with our study's results, suggesting that gymnasts develop movement-specific strategies to coordinate body mass centers differently at the beginning of force handstand movement, with eyes open and closed. Pryhoda, Newell, Wilson, & Irwin (2022) have determined that different balance control strategies are employed in handstand and standing postures.

The analysis conducted in the right and left planes at 90° with eyes open and eyes closed revealed statistically significant correlations, both in the negative and positive directions. Interestingly, we observed that contrary to the increase in anterior-posterior right-left isometric arm muscle force, there was a decrease in coordinate values dependent on shoulder angle and shoulder Y. Moreover, in conjunction with the increase in right and left arm isometric arm muscle force, there was an increase in coordinate values dependent on feet Y. This observation suggests a potential stimulation for forward motion of the head, back, and hips, as well as upward motion of the feet, aiming to achieve the desired handstand position while maintaining the current position of shoulder areas at 90° of the press to handstand movement.

To further explore this phenomenon, Grabowiecki, Rum, Laudani, & Vannozzi (2021) conducted a study on the biomechanical characteristics of handstand walking initiation. They concluded that a successful handstand walking initiation required a shift of the center of mass forward and towards the stance hand, accompanied

by a lateral and posterior shift of the center of pressure. These findings align with the results of our study, suggesting a similar mechanism at play.

Our study revealed differences between the 90° handstand with eyes open and the 90° handstand with eyes closed. At 90° (i.e., the second phase of the press to handstand) with eyes open, gymnasts narrowed their shoulder angles in the right plane by utilizing right and left arm posterior isometric muscle force to achieve the desired movement position. Conversely, when performing the handstand with eyes closed, gymnasts employed their right arm posterior, right arm anterior, and left arm posterior isometric muscle force to adjust shoulder Y to the desired motion position, thus reaching the desired motion angle.

The high level of experience and elite status of the gymnasts in our study likely played a significant role in these findings. Similarly, Sobera, Serafin & Rutkowska-Kucharska (2019) concluded in their study that more experienced gymnasts concentrate on handstand movement by minimizing medial-lateral body swing and anterior-posterior body swings. Additionally, Omorczyk, Bujas, Puszczałowska-Lizis, & Biskup (2018) found that more experienced gymnasts performed better in both the handstand and standing positions compared to young athletes.

These observations regarding the 90° position of the press to handstand may stem from gymnasts' efforts to utilize their force more economically and employ techniques that are more suitable before advancing to 180°. In line with the data obtained from our study, it can be inferred that gymnasts execute specific muscle movements tailored to the position in their handstand movements performed at different angles. Accordingly, gymnasts may engage in specific muscle activations tailored to varying conditions in the handstand position (Kochanowicz, Niespodziński, Mieszkowski, Marina, Kochanowicz & Zasada, 2019).

At 90° with eyes closed, it was observed that the absence of visual input prompted gymnasts to actively engage their right arm anterior muscle force in the right plane and their left arm posterior muscle force in the left plane, in addition to their anterior-posterior arm muscles that are actively used when performing the motion with eyes open. The gymnasts' proficiency in positioning their body parts at a correct angle at 90° of the press to handstand, whether with eyes open or closed, can serve as an important predictor of a successful handstand.

In a study conducted by Kochanowicz et al. (2016) on the biomechanical indicators of the forward handspring vault and maximal power of the lower limbs, it was found that the angles of the hip joint in the second phase of the flight and when the hands touched the vault surface might influence the received score. Additionally, athletes' ability to maintain their bodies in the correct position before the handstand at a 90° angle, whether with eyes open or closed, may involve other control systems.

In their study, Gautier, Thouvarecq & Chollet (2007) concluded that both the central-peripheral angle of view and other balance control systems may play a crucial role in the postural regulation of handstand movement.

In our study, the analysis conducted in the right and left planes at 180° with eyes open and eyes closed showed a statistically significant correlation both in the negative and positive direction. This might be attributed to gymnasts attempting to achieve the desired balance position in handstand by engaging various muscle groups, including the arm muscles, in the right-left planes, with

both eyes open and closed. In this regard, Kochanowicz, Niespodziński, Marina, Mieszkowski, Biskup, & Kochanowicz (2018) concluded in their study that several muscle groups actively contributed to maintaining balance in handstand. Additionally, postural weight can also play a crucial role in maintaining the desired balance in the right-left planes. Thomas et al. (2023) concluded in their study that postural weight played a significant role in handstands on the sagittal plane. The reflex developed by the neck may also be pivotal in gymnasts' ability to maintain balance stability in the 1800 handstand position. During the handstand movement, the neck area can serve as an important guide for keeping the body in the correct position. For this purpose, Asseman and Gahéry's (2005) study found that the tonic neck reflex may play a significant role in maintaining gymnasts in the correct posture during handstands. The conclusions drawn in the aforementioned studies align with our study. However, our study identified some differences between handstands performed with eyes open and those performed with eyes closed. Specifically, our study revealed that gymnasts utilized their right arm posterior isometric arm muscle force on the right plane to maintain the desired balance in handstands with eyes open, whereas they employed their right arm posterior, right arm anterior, left arm anterior, and left arm posterior muscle force to maintain balance in handstands with eyes closed. Furthermore, our study observed that, in contrast to the increase in isometric arm muscle force with eyes closed, there was a decrease in shoulder angles and hip X levels. This phenomenon may occur because the central nervous system enhances its influence on the arm muscles to maintain the desired balance when visual input is absent during handstand performance with eyes closed. Gymnasts may develop various strategies to sustain the desired balance at 180° with eyes closed by interpreting stimuli received by the central nervous system from the peripheral nervous system. Specifically, the feedback system comprising the brain, cerebellum, afferent (sensory), and efferent (motor) nerves likely plays a crucial role in shaping these strategies.

In the handstand, the static balance created by body mass centers and sudden changes in balance can trigger a sequence of muscular reactions, primarily dependent on the afferent nervous system and subsequently on central generators (Ergen, Ülkar & Eraslan, 2007). Additionally, apart from the neural strategies developed by gymnasts when performing handstands with eyes closed, the vestibular system, a fundamental component of proprioception, can also significantly contribute to balance in blindfolded handstands. This contribution may primarily involve controlling body weight.In support of this notion, a study conducted by Jessop and McFadyen (2008) concluded that the vestibular system stimulates an increase in body weight during the standing posture with one eye closed, facilitating the body to maintain balance. In addition to this finding from our study, factors such as executing the motion with proper technique, depending on individual differences, may also play a significant role. A study by Blenkinsop, Pain, and Hiley (2017) on balance control strategies in handstands revealed that while the central nervous system employed various control strategies during a handstand balance trial, these strategies were applied individually rather than simultaneously.

Moreover, in another study by Mizutori, Kashiwagi, Hakamada, Tachibana, & Funato (2021), it was observed that some

gymnasts generated larger shoulder flexion moments during handstands, whereas others exhibited larger hip flexion moments.

In our study, it was observed that the narrowing of the shoulder and hip angles (due to an increase in anterior-posterior isometric arm force) in the handstand with eyes closed exemplifies correct handstand technique. Considering that artistic gymnastics is a sport where champions are determined by subtle nuances, the angular positions of the shoulders and hips, influenced by gravity, can be crucial in teaching gymnasts the correct handstand skill (Koçak, 2019).

However, contrary to the conclusion reached in our study, Puszczałowska-Lizis and Omorczyk (2019) found in their research on body balance in standing position and handstands in gymnasts that disabling visual control during free standing, as well as adopting a handstand position, resulted in a deterioration of stability indices. This finding contrasts with the results of our study. Additionally, Isotalo, Kapoula, Feret, Gauchon, Zamfirescu, & Gagey (2004) concluded in their study that unilateral vision in postural control may provide stability equal to or even better than bilateral vision.

Despite the divergent results from these studies, artistic gymnastics remains a sport characterized by intensive training practices. Therefore, gymnasts should be exposed to higher workloads to attain the desired level of proficiency in movements requiring a fixed position such as the handstand (Malíř, Chrudimský, Šteffl, & Stastny, 2023).

LIMITATIONS

- Evaluation of athletes within one single day due to their involvement in intense competition schedules.
- Some athletes exhibited agitated attitudes during handstand movement.
- Athletes experienced excessive balance losses during handstand movement.

Challenges arose in obtaining the necessary permits to work.

CONCLUSIONS

In this study, we conducted an in-depth analysis of the positional kinematics of the press to handstand, a fundamental movement in aesthetic sports such as artistic gymnastics, where elegance converges with power. Proper body positioning on the floor at the outset of the movement is crucial for gymnasts to execute the press to handstand accurately, efficiently, and with correct technique.

We concluded in our study that a wider triangle formed by the gymnasts' shoulders, hips, and feet in the starting position of the press to handstand with eyes open was indicative of poor starting technique. Additionally, we observed that at 90°, gymnasts' proprioception functioned differently in the right and left planes when performing a handstand with eyes open and eyes closed, leading to variations in angle usage and differences in the utilization of right-left isometric arm muscle force.

Furthermore, we found that gymnasts utilized their right-left isometric arm muscle force and adjusted their angular position in the right-left planes to maintain balance in the handstand at 180°, irrespective of whether their eyes were open or closed.

Our study revealed that gymnasts effectively utilized proprioception during the press to handstand, regardless of whether their eyes were open or closed. Additionally, we concluded that significant differences in angle positions during the press to handstand, attributed to variations in

proprioception and individual preferences, may arise due to discrepancies in isometric arm muscle force.

Gymnasts actively engage their muscles to maintain the correct position in the press to handstand, particularly when performing with their eyes closed. Based on the findings of our study, gymnastics coaches should incorporate blindfolded practices into their athletes' training regimens, especially focusing on handstand and related movements. This approach could positively contribute to both neuromuscular adaptation and proprioceptive awareness.

Moreover, by directing their attention solely on the movement, gymnasts can shield themselves from the detrimental effects of environmental stimuli.

ETHICAL STATEMENTS

Necessary permissions for conducting the study were obtained from the Turkish Ministry of Youth and Sports and the Turkish Gymnastics Federation. For our study, the necessary permissions were obtained from the Gazi University Ethics Commission with the number E-77082166-604.01.02-608841.

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DID THE CHANGES MADE TO THE 2022-2024 CODE OF POINTS IN TRAMPOLINE GYMNASTICS CHANGE THE SCORE OF THE GYMNASTS?

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Abstract

The evaluation rules for trampoline gymnastics were revised by the technical committee post-Tokyo 2020 Olympics, notably affecting the qualifying round. Previously, only four elements were considered for difficulty points in the first routine, but now all elements count in both routines. To assess the impact, data from the 28th/29th FIG Trampoline Gymnastics World Age Group Competitions and 35th/36th FIG Trampoline Gymnastics World Championships in 2021/2022 were analyzed. A t-test compared scores in Execution (E), Difficulty (D), Time Of Flight (TOF), and Horizontal Displacement (HD) between 2021 and 2022. In the senior men's category, average values increased in D, HD, and total scores in 2022, with significant differences in Execution and near-significant in TOF scores. Across all other categories, mean values of D, E, TOF, HD, and total scores rose in 2022, though without statistical significance. The trend towards higher scores under the new rules suggests their influence, yet unexplored factors may also play a role. Further research is needed for a comprehensive understanding.

Keywords: *trampoline; gymnastics; routine; evaluation rules.*

INTRODUCTION

All sports disciplines have undergone significant changes since their inception, evolving into their modern forms today. It is well-established that the rules governing these sports continue to be updated over the years for various reasons, including addressing issues, advancements in athletes' technical abilities, the incorporation of new technologies, and enhancing spectator enjoyment. It remains a subject of inquiry for sports scientists to assess the extent to which these objectives have been achieved following these updates, and whether any unforeseen effects have emerged.

For instance, a study in the literature examines the impact of the Spanish Basketball Federation's rule changes in mini basketball (Arias, Argudo & Alonso, 2009). The rules governing various disciplines within the Fédération Internationale de Gymnastique (FIG) are regularly revised by the technical committees of each discipline after every Olympic cycle. Consequently, the frequency of workshops provided to coaches increases after each edition of the Olympic Games, and international judges must update their knowledge, retake exams, and demonstrate continued proficiency.

Despite the implementation of rigorous evaluation criteria, a significant portion of the scoring system in all gymnastics disciplines still necessitates a degree of subjectivity. Therefore, researching and interpreting the effects of these rules in gymnastics requires a multidimensional approach and substantial expertise. Kerr and Obell undertook such investigations in a study published years after the introduction of new rules, which laid the groundwork for radical changes during a period when the maximum score in artistic gymnastics was 10 (Kerr & Obel, 2015).

Trampoline gymnastics, in particular, has undergone significant changes in the last decade with the integration of technological measuring devices and the introduction of new scoring criteria (FIG, 2021). These changes represent important factors that can influence a gymnast's ranking. For instance, the total score distribution differs when scoring does not include assessments of all element heights or the landing point on the trampoline bed. Consequently, following each Olympic Games, coaches and athletes must thoroughly acquaint themselves with the updated rules, review gymnastic routines in light of these changes, and devise strategic plans accordingly.

Despite trampoline gymnastics' increasing popularity as an Olympic discipline and the notable revisions to evaluation rules in recent years, scientific research in this field remains relatively limited. This scarcity of research may stem from the intricate nature of the evaluation rules, which may not be easily comprehensible to non-gymnasts, despite the branch's high entertainment value.

When reviewing current studies on trampoline gymnastics in the literature, it is evident that processes related to injuries are addressed (Kirişçi & Alpkaya, 2019). For instance, Patel, McGregor, Williams, Cumming, and Williams (2021) discovered that trampoline gymnasts face a higher risk of injury under certain circumstances, such as growth spurts or increased workloads. An intriguing study conducted in the United Kingdom aimed to explore the experiences of trampoline and artistic gymnasts as they returned to training after a hiatus due to the pandemic (Patel, McGregor, Cumming, Williams, & Williams, 2022).

There are studies investigating the physical characteristics of both artistic gymnasts and trampoline gymnasts (Siahkouhian, Aalizadeh, & Esmaeilzade, 2013), as well as research examining muscle activity during trampoline movements (Matsushima, 2023). Aydin, Gündoğan, and Demirkan (2023) delved into the effects of trampoline and artistic gymnastics training on various biomotor abilities. Additionally, a groundbreaking study investigated whether movements could be detected using machine learning, potentially altering the landscape of trampoline gymnastics judging in the future, with largely successful results (Woltmann, Hartmann, Lehner, Rausch, & Ferger, 2023).

While all these studies are significant in terms of advancing the discipline, it is equally crucial to research and interpret the potential outcomes of rule changes to provide guidance for coaches and athletes.

When examining the latest Code of Points in Trampoline Gymnastics published by the FIG (FIG, 2021), the most significant change is observed in the routines during the qualifying round. According to this alteration, the difficulty value of four elements in the first routine of the qualifying round has been removed, and now two voluntary routines are performed in qualification one. Under the new rules, the routine with the best result is considered

valid, meaning that the difficulty value of all movements is evaluated in both routines. Additionally, while previously the combined score of the 1st and 2nd routines determined whether gymnasts progressed to the next round, now only the routine yielding the highest score among the two is valid under the new rules. This new practice applies to both gymnasts competing in the senior category and young gymnasts competing in the 17-21 years old age group category. Of course, during competition implementation, other changes have been made, such as determining the total number of competitors to determine the number of gymnasts qualifying for the second round or updating warm-up times (FIG, 2021).

However, it is believed that none of these changes will impact the training and competition strategies of gymnasts as significantly as the alteration in qualification one. Therefore, this study was designed with the observation and consideration that the aforementioned rule change may reveal different parameters compared to the past in the general competition performance of gymnasts and in determining the winning gymnasts. The study aims to compare the results of the Trampoline Gymnastics World Championship and the World Age Groups Competitions, which were conducted according to the 2017-2020 Code of Points (FIG, 2016) and the 2022-2024 Code of Points (FIG, 2021), and to contribute to the studies of coaches, athletes, and technical committees by interpreting the potential differences.

METHODS

The data for this study comprises the competition results of athletes who participated in four competitions: the 28th FIG Trampoline Gymnastics World Age Group Competitions (17-21 age group) and the 35th FIG Trampoline Gymnastics World Championships tournament held in Baku in 2021, as well as the 29th FIG Trampoline Gymnastics World Age Group Competitions and the 36th FIG Trampoline Gymnastics World Championships tournaments held in Sofia in 2022. These results are publicly available on the official website of the FIG under the results tab (https://www.gymnastics.sport/site/events/searchresults.php) [Accessed on 20.07.2023]. The tournament results, including difficulty score (D), execution score (E), time of flight (TOF), horizontal displacement score (HD), and total scores, were utilized as data.

At the 28th FIG Trampoline Gymnastics World Age Group Competitions held in 2021, data from 49 men and 47 women in the 17-21 age group were analyzed, along with data from 78 men and 54 women at the 35th FIG Trampoline Gymnastics World Championships. Similarly, at the 29th FIG Trampoline Gymnastics World Age Group Competitions held in 2022, data from 65 men and 49 women in the 17-21 age group were evaluated, alongside data from 99 men and 73 women at the 36th FIG Trampoline Gymnastics World Championships.

In 2021, the second routine in the qualifying round was taken into consideration, whereas in 2022, the highest score was evaluated, consistent with the official results. Due to the rule change, the difficulty score (D), execution score (E), time of flight (TOF), horizontal displacement score (HD), and total scores, which constitute the results of two different tournaments (2021-2022), were statistically compared.

Descriptive statistics of the data are presented as mean ± standard deviation, and statistical significance was determined as p

< 0.05. To assess whether the data followed a normal distribution, skewness and kurtosis values were calculated, and Shapiro-Wilk normality tests were performed. Normal distribution was confirmed when p > 0.05.

The independent samples t-test was employed to compare the result scores between women's and men's world championships in age groups, as well as between women's and men's world championships in the senior category for the years 2021 and 2022. Effect sizes were assessed using Glass's delta (δ). For data analysis, the SPSS Statistics Ver. 29 software package (IBM Corp. Release 2022. IBM SPSS Statistics for Windows, Version 29.0. Armonk, NY) was used.

RESULTS

Women's D (9.19±3.15), E (12.23±4.34), TOF (12.29±4.16), HD (7.90±2.76), and total scores (41.61±14.23) of the age groups of the World Age Group Competitions held in 2021 did not have a statistically significant difference D (9.66±2.98), E (13.26±3.68), TOF (13.23±3.48), HD (8.40±2.14), and total scores (44.55±11.90) compared with the competition held in 2022 (p>.05). Comparisons of average D, E, TOF, HD, and total scores from the Championships held in 2021 and 2022 are presented in Figure 1.

The men's D (11.17±4.44), E (11.72±4.61), TOF (12.68±4.83), HD (7.29±2.89), and total scores (42.86±16.61) of the age groups of the World Age Group Competitions held in 2021 did not have a statistically significant difference D (11.98±3.85), E (12.70±4.12), TOF (13.59±4.27), HD (7.86±2.56), and total scores (45.49±15.29) compared with the competition held in 2022 (p>.05). Comparisons of average D, E, TOF, HD, and total scores from the Championships held in 2021 and 2022 are presented in Figure 2.

The women's D (11.22±3.66), E (13.09±4.28), TOF (12.89±4.07), HD (7.98±2.62), and total scores (45.12±14.38) of the senior category of the World Championship held in 2021 did not have a statistically significant difference D (11.84±3.08), E (14.30±2.79), TOF (13.94±2.53), HD (8.76±1.50), and total scores (48.83±9.33) compared with the competition held in 2022 (p>.05). Comparisons of average from the championships held in 2021 and 2022 are presented in Figure 3.

The men's E score of the championship held in 2021 was lower (12.037±4.50) compared with 2022 (13.290±3.24), with a statistically significant increase of 1.253 (95% CI: [-2.45 / -.056] t(135.09)=-2.070, p=.040, δ= 0.386). The TOF score of the championship held in 2021 was lower (13.517±4.85) compared with 2022 (14.809±3.49), with a near statistically significant increase of 1.291 (95% CI: [-2.580/ -.003] t(134.89)=-1.982, p=.050, δ= 0.370).

The men's D (13.25±4.72), HD (7.65±2.85), and total scores (46.44±16.81) of the senior category of the World Championship held in 2021 did not have a statistically significant difference D (13.93±3.76), HD (8.34±2.01), and total scores (50.36±12.16) compared with the competition held in 2022 (p>.05). Comparisons of average D, E, TOF, HD, and total scores from the Championships held in 2021 and 2022 are presented in Figure 4.

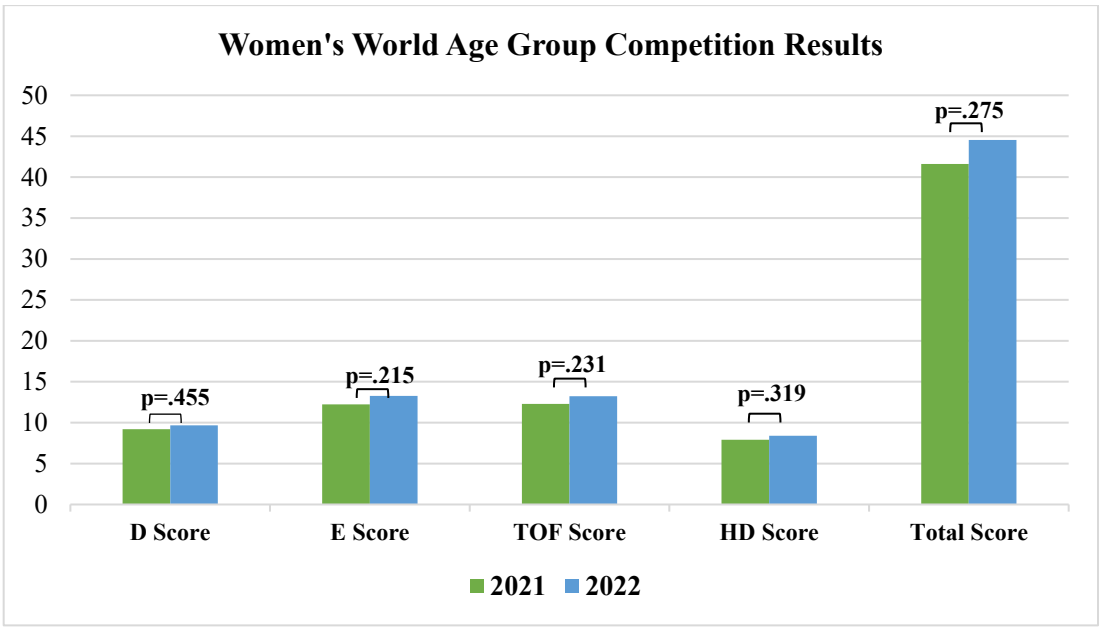

Figure 1: Women's World Age Group Competition Results
D: Difficulty, E: Execution, TOF: Time of Flight, HD: Horizontal Displacement

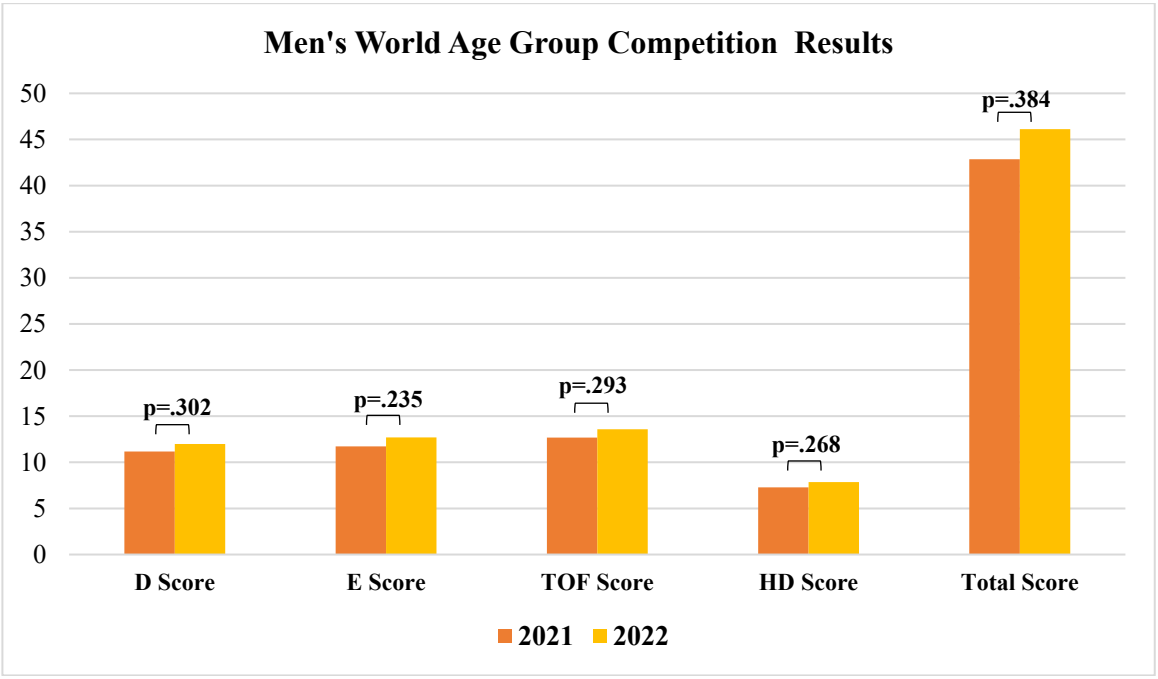

Figure 2: Men's World Age Group Competition Results
D: Difficulty, E: Execution, TOF: Time of Flight, HD: Horizontal Displacement

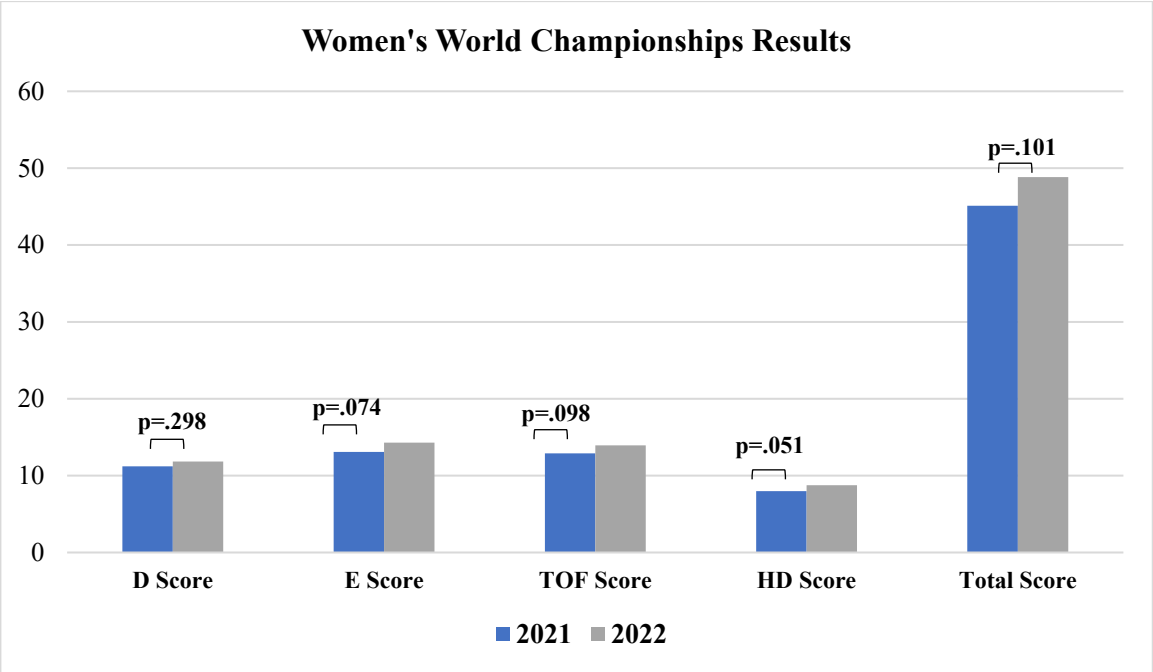

Figure 3: Women's World Championships Results
D: Difficulty, E: Execution, TOF: Time of Flight, HD: Horizontal Displacement

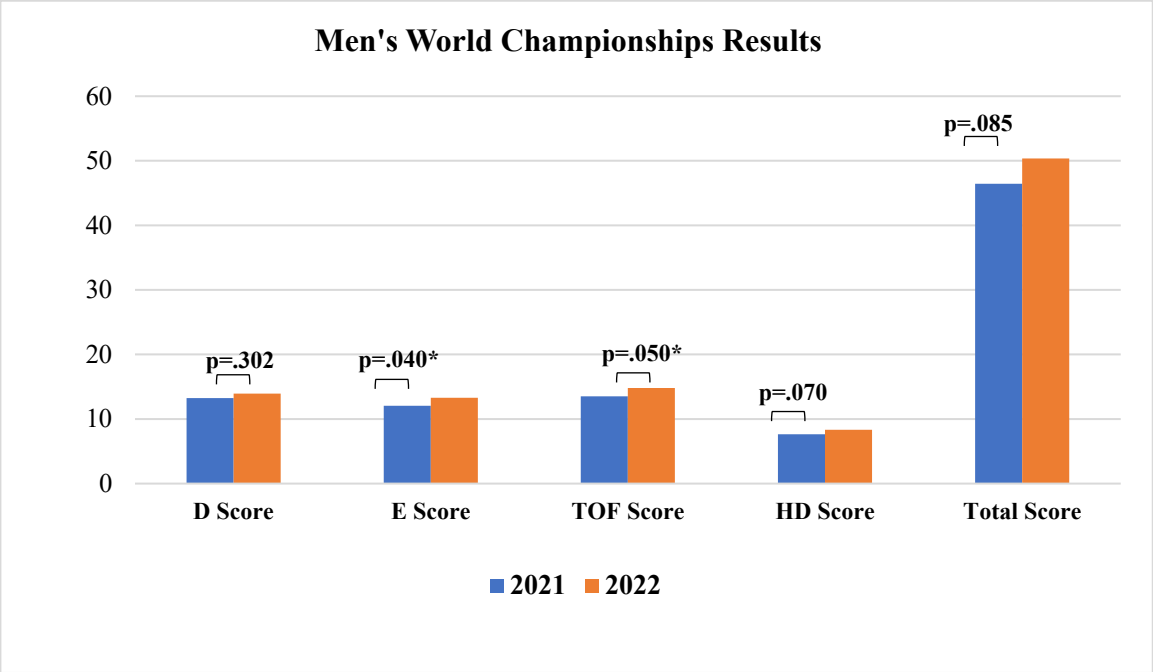

Figure 4: Men's World Championships Results
D: Difficulty E: Execution, TOF: Time of Flight, HD: Horizontal Displacement

DISCUSSION

In the present study, the results of trampoline gymnastics World Age Group competitions and World Championships were compared before and after the update of evaluation rules. The study was designed in this manner due to the curiosity surrounding whether the change in evaluation rules would impact the athletes' scores. According to the statistical analyses, the only category with significant results

was identified as the E score of senior men, which was found to be higher in the evaluation conducted according to the new rules. Additionally, the TOF scores of the same group yielded a p-value of exactly 0.05, and it was observed that the TOF averages of the 36th FIG Trampoline Gymnastics World Championships were higher.

While interpreting the results, it would not be adequate to rely solely on statistically significant findings because scores in trampoline gymnastics can be highly correlated. Furthermore, it should be noted that competitors adopt different strategies based on different rules. The score of the second routines in the 2021 qualifiers and the best score in the 2022 qualifiers carry different implications due to the rule change. Therefore, it would be prudent not to consider these scores as exact equivalents.

Upon examining all score types of the World Championships held in 2021 and 2022 for senior men, it is evident that there is a higher average in each score type in the 2022 competition. Moreover, the higher average score observed in the 2022 World Championship is consistent across both genders and extends to the results of older female athletes and the World Age Groups Championship (17-21 years age category). Additionally, when comparing the results of senior female athletes in the 2022 World Championship with those of female and male athletes in the World Age Group Competitions (17-21 years age category) in 2022, it is observed that all score types tend to increase compared to the previous year.

In this regard, it can be inferred that routines developed in accordance with the current rules outlined in the 2022-2024 Code of Points for Trampoline Gymnastics contribute to the presentation of higher-quality routines. Although most of these results lack statistical significance, they hold significant importance in a sport like gymnastics, where even a 0.1-point difference can impact podium finishes. Another critical issue to consider is that the increase in scores in 2022 occurred despite the absence of two top-level countries, namely Russia and Belarus, which typically secure podium positions.

It has been noted in the literature that increasing the difficulty score will positively contribute to the total score; however, it is crucial to ensure that points are not lost from other score types in the process (Koca Kosova & Kosova, 2021). According to the current rules, the requirement for athletes to perform two voluntary routines in the qualifying round to advance to the next round further emphasizes this necessity. Upon examining the results of the current study, it is evident that competitors in all categories are able to meet this demanding requirement.

Under the 2017-2020 Code of Points, athletes often refrained from incorporating very risky and difficult moves into their routines during the qualifying round. Despite this, athletes still had the opportunity to progress to the next round, with the execution score holding significant importance in the first routines of the qualifying round. However, as indicated by the results, it will be challenging to advance through the qualifying round with a low difficulty score under the current rules.

Although world age group competitions facilitate the participation of more countries in trampoline gymnastics competitions (Vicente-Mariño, 2021), the 17-21 years age category can be viewed as a preparatory stage for the senior category. Consequently, the evaluation rules for this age group were slightly different from each other in the previous cycle but have become aligned in

the current cycle. The absence of a second qualification phase in age group competitions, and the variation in qualification 2 rules based on the number of registered athletes in senior competitions, may lead to the adoption of different strategies in these groups. For instance, since there is only one opportunity to qualify for the finals in age groups, athletes may opt for higher-risk routines in the qualifying round. Conversely, for seniors, different routines may be employed to qualify for the second round and finals. The results of the current study did not reveal any conflicting outcomes in this regard, and the increasing trend in score types appears to be similar for both the 17-21 years age group and seniors.

One possible reason for the increase in average difficulty scores across all categories in 2022 is that athletes have two opportunities to perform relatively challenging routines, with no penalties if they fall during one of these attempts. This new rule may have provided coaches and athletes with greater flexibility. Consequently, athletes may have incorporated movements that they have not yet mastered perfectly into their routines, as they now have the opportunity to present both secure and riskier routines in their performances. Additionally, the increase in both other score types and difficulty scores may be attributed to the shift from focusing on at least two different routine types under the previous rules to concentrating on a single routine under the current rules. The inability to repeat movements with a difficulty score counted in the first routine of the previous cycle may have also contributed to lower average difficulty scores in the routines evaluated under the new cycle. However, from another perspective, this newfound freedom and risk-taking may also lead to an increase in incomplete routines. Although the number of completed moves is not explicitly stated in the result lists, a high number of athletes falling without completing 10 moves was apparent in the qualifying rounds of competitions in 2022, evident from the scores to anyone familiar with trampoline gymnastics. Hence, it becomes crucial for coaches and athletes to decide on the level of risk they are willing to take. While making this decision, prioritizing safety should be the first consideration, followed by assessing the likelihood of qualifying for the next round if the risk is undertaken. Observing the performance of potential competitors can be instrumental in this decision-making process.

The issue of optimal risk-taking when designing routines is critical, both under the rules of the current cycle and previous cycles, despite the different characteristics of various routine types (Kosova & Koca Kosova, 2021).

The scarcity of studies conducted in the literature on trampoline gymnastics, and even those that have been conducted being interpreted based on previous evaluation rules, presents challenges in leveraging their findings, particularly in the discussion section of the current study. This circumstance can be identified as a significant limitation of the study.

CONCLUSIONS

In conclusion, the current study revealed that the significant rule changes implemented in the last cycle have the potential to induce notable alterations in both training content and competition scores. The trend toward increasing scores in each score type within athletes' routines represents a significant development for a discipline that encompasses numerous score

types. However, as discussed in the preceding section, while the rule update may enhance the quality of routines, it may also lead to an increased incidence of incomplete routines and subsequently, a higher risk of injury among gymnasts.

Future studies could explore the extent to which current rules influence both the practice of trampoline gymnastics and the risk of injury.

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ANALYSIS OF SCIENTIFIC PRODUCTION IN STREET SPORTS WITH ACROBATIC COMPONENTS

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Abstract

In recent years, the number of practitioners of disciplines such as parkour, break dance or calisthenics (freestyle or street workout) has increased. These disciplines share common characteristics, such as an unregulated street origin and a focus on acrobatics. This study aimed to analyze the state of scientific publications related to these acrobatic street sports. A bibliometric analysis was conducted, applying traditional bibliometric laws to scientific documentation found in journals indexed in WoS and Scopus. Data processing and visualization were performed using Bibliometrix and Excel. A total of 199 articles published between 1984 and 2024 were identified, indicating exponential growth. Among these, 139 papers were related to parkour, 48 to breakdance, and 12 to street workout. A review of 158 journals revealed that they contained related publications, although their distribution did not conform to Bradford's model, showig only two areas. Among 417 authors identified, 22 were deemed prolific and 12 prominent. France emerged as the most prolific country, followed by the USA. The 553 author keywords were categorized into three groups, each associated with one of the sports. The 26 most cited papers were selected as relevant, demonstrating a correlation between the increase in publications and the popularization of these sports, largely due to television exposure. The "International Journal of Sport Policy and Politics" emerged as the most prolific journal. The most relevant authors identified in each sport were Signey Grosprêtre (parkour); Max Daniel Kauther and Christian Wedemeyer (breakdance); and Javier Sanchez-Martinez (street workout).

Keywords: *Acrobatics; sports; physical activity; parkour; break dance; street workout.*

INTRODUCTION

Any acrobatic movement involves inversions and rotations of the body in space. The quintessential basic skill involves a 360-degree compound turn around the transverse axis while maintaining continuous contact with the apparatus or surface. The term "rolls" refers to this group of very basic acrobatic skills practiced in certain sports

disciplines. By extension, it is also used to describe a set of motor activities of indeterminate acrobatic character practiced in different contexts, which serve as the foundation for learning more advanced elements (Cartoni & Putzu, 1990).

In recent years, there has been a trend towards the practice of sports as a recreational opportunity of an urban nature, developed outdoors (Salazar, 2020). These activities are far from institutionalized, regulated, and organized "sports" (Salazar, 2020). Instead, they are more alternative cultural manifestations of a motor nature, rather than exercises or movements aimed at comparison or competition (Salazar, 2020). Promoted by concerns or expressive and alternative currents, break dance, parkour, and calisthenics are names that identify a series of motor practices of eminently urban origin and development, which are very current and constantly gaining followers (Mollenhauer, 2021; Pagnon, Faity, Maldonado, Daout, & Grospretre, 2022; Yang, Bai, & Wei, 2022).

The different definitions and conceptualizations of the term "acrobatics" fluctuate between art, motor skills, sport, and even ritual. The dictionary of the Royal Academy of the Spanish Language (Real Academia Española, 2022) refers to it with three meanings that are not very clear:

1. f. Profession or activity of the acrobat. U. t. in sent. fig.,

2. f. Each of the exercises performed by an acrobat. U. t. in sent. fig,

3. f. Each of the spectacular evolutions performed by an aviator in the air.

In deeper definitions more specific to the sports field, acrobatic activities refer to movements of the body or in conjunction with some device, involving rotations, inversions, jumps, and aerial trajectories, always endowed with a certain degree of spectacularity and/or risk (Pozzo & Studeny, 1987). Definitions also link these activities to the displacement and trajectories of the performer, referring to "control of the body" and "control of the body in space" (Rico & Brasileiro, 2002).

While neither parkour nor break dance originally intended to include acrobatic skills as an objective, the expressive possibilities offered by movements in which the body holds an inverted position or passes through it when performing a turn or flip have made their presence constant in the practice at a certain level of performance.

In recent years, there has been a significant rise in sports practices initiated by individual interests rather than governmental or institutional efforts, achieving substantial social impact among young people, primarily due to the influence and reach of social networks (Herrera, 2012).

Some of these motor practices have a high acrobatic component, characterized by spectacularity and risk, making them particularly well-suited for success on social networks, which has fueled their rapid popularity growth (García & Aguado, 2009).

Parkour, break dance, and calisthenics (recently known in many places as street workout) are examples of acrobatic sports practices that have proliferated on social networks. Originating from the streets, these activities were initiated by groups of enthusiasts who developed ways of moving or exercising the body that are ideal for dissemination and audiovisual enjoyment (Paolillo, Ghule, & Harper, 2019).

Parkour is a motor activity generated from the natural method developed by Georges Hébert at the beginning of the 20th century. It consists of moving fluidly from one point to another and emerged in the early 1990s in France (Pagnon et al., 2022),

emphasizing the efficiency of displacement. Derived from parkour, freerunning embodies freedom of movement and includes many acrobatic maneuvers. It maintains the essence of displacement but incorporates other practices during the course, and its mentality is very different.

According to Yang et al. (2022), break dance is a form of street dance that emerged in the neighborhoods of New York in the 1960s, although it had its greatest boom and expansion to Europe in the 1980s. It was born as part of the hip-hop culture and has been growing and expanding its competitive capacity, being incorporated for the first time in the upcoming Olympic Games in Paris 2024 (Wei et al., 2022).

Calisthenics is a form of traditional functional work in which the weight of one's own body is used as a workload (Mollenhauer, 2021). In recent years, public facilities and groups of practitioners have proliferated alongside the advancement of social networks. Simultaneously, the practice has been "sportified" by organizing movements and techniques around competition rules that allow for comparison between executions (Morozova, Zinchuk, Dorontsev, & Kashirsky, 2019).

This discipline, which began as strength training, has been incorporating dynamic movements with a greater acrobatic component, and its health benefits have been sought in diverse and disparate populations. Calisthenics has been structured into different modalities, the most related to acrobatics being the freestyle modality, also known as "street workout" (‘Entrenamiento callejero’, 2022).

Figures provide a quick idea of the popular reach of these sport disciplines. A simple search in common Internet search engines reveals millions of references when entering the names of these three sports. There are more than twenty-seven million references for "calisthenics," fifty-six million for "parkour," and more than two hundred and sixty million for "break dance."

These sports modalities appear as an evolution, simplification, or concretization of other similar, more extensive, traditional, or complex activities. For example, calisthenics includes many movements found in the scoring Artistic Gymnastics code of points (FIG - Fédération Internationale de Gymnastique, 2020b, 2020a). A similar situation occurs with the other sports disciplines, where the intention and/or form differ notably, at least initially, from the competitive concerns of gymnastic-acrobatic sports disciplines. However, in recent years, they have entered the competitive world, establishing scoring and comparison systems that enhance performance and development, albeit at the cost of losing part of their initial essence or purpose.

Considered as a competitive sport discipline or as a street motor expression, there is no doubt that interest in these activities and the number of practitioners have been growing in recent years. Therefore, it is necessary to understand the scope these emerging modalities present to researchers. In recent years, bibliometric analysis has become popular as a method for determining the current state of research in a specific field of study. This type of analysis can be found in other topics, such as mountain tourism (Ng, 2022).

The first approach was to determine which acrobatic disciplines have a fully street origin and do not depend on an implement. After an extensive process of review and inquiry, parkour, freerunning, breakdancing, and calisthenics were selected. Disciplines such as skateboarding, which depend on specific equipment like a

skateboard, were discarded. Some of these disciplines dependent on an implement are categorized as Sliz sports (León, 2002) and were not included in the review for the aforementioned reasons.

Given the growing public interest in these disciplines, it is considered appropriate to perform a bibliometric analysis. The aim is to determine whether there is also a growing interest in street acrobatic disciplines within the scientific community, identify current research trends, and discover which authors and journals are the most prolific and influential. Additionally, the analysis seeks to reveal the most relevant keywords, the most prolific countries and affiliations, and the most cited documents.

METHODS

In this section, we will explain the various stages followed to perform the bibliometric analysis. A bibliographic search of publications related to the subject matter was carried out in journals indexed in the Web of Science (WoS) of Clarivate Analytics and Scopus databases. These databases are among the most widely used sources by researchers (Cascajares, Alcayde, Salmerón-Manzano, & Manzano-Agugliaro, 2021; Díaz, Teixidó, Gil, Cabeza, & Aras, 2021) when performing bibliometric analyses due to the large number of journals indexed in them and the extensive information offered on journals, authors, and articles (Archambault, Campbell, Gingras, & Larivière, 2009; Jamali, Md Zain, Samsudin, & Ale Ebrahim, 2015).

The following search vector was used in the WoS database: *TI=("break dance") OR TI=(breakdance) OR TI=(break-dance) OR TI=(parkour) OR TI=(freerun*) OR AK=("break dance") OR AK=(breakdance) OR AK=(break-dance) OR AK=(parkour) OR AK=(freerun*) OR (TI=(gymnast*) OR TI=(acrobat*) OR AB=(gymnast*) OR AB=(acrobat*) OR AK=(gymnast*) OR AK=(acrobat*)) AND (TI=(calisthenic*) OR AB=(calisthenic*) OR AK=(calisthenic*)) OR TI=("street workout") OR AK=("street workout")* as a means of obtaining the largest possible number of publications on the subject. The tags "TI", "AB" and "AK" were used, locating the searched terms only in title, abstract and author keywords. The search was limited to articles and reviews within the Core Collection Database of WoS, and 196 documents were obtained.

In the Scopus database, the search was also limited to articles and reviews, and the "TITLE" tag was used to locate the search terms in the titles of the publications. The search vector used was: *TITLE("break dance") OR TITLE(breakdance) OR TITLE(break-dance) OR TITLE(parkour) OR TITLE(freerun*) OR ((TITLE-ABS(gymnast*) OR TITLE-ABS(acrobat*)) AND TITLE(calisthenic*)) OR TITLE("street workout")*, resulting in 182 articles. Keywords were not included in this search because it does not allow limiting to author keywords. By including indexed keywords, many of the resulting articles are not related to the subject matter.

Both searches were carried out on December 20, 2023. The results were exported in their respective formats: WoS formats as ".xlsx" and plain text ".txt", and Scopus as ".csv". The exported searches were processed using Microsoft® Excel® for Microsoft Office Professional Plus 2019, RStudio 2022.7.2.576 (RStudio Team, 2020), and the Bibliometrix data package (Aria & Cuccurullo, 2017). Scripts were used to automatically detect 92 duplicates, resulting in a total of 268 documents from both databases. The remaining publications

underwent manual review by two researchers, KLG and YRR. Twenty-five documents were discarded due to duplicates, and 62 documents were excluded based on title or abstract not being related to the selected topic. Disagreements between the two researchers were resolved through discussion. The total number of documents considered for the bibliometric analysis was 199 publications. This entire process is represented in Figure 1.

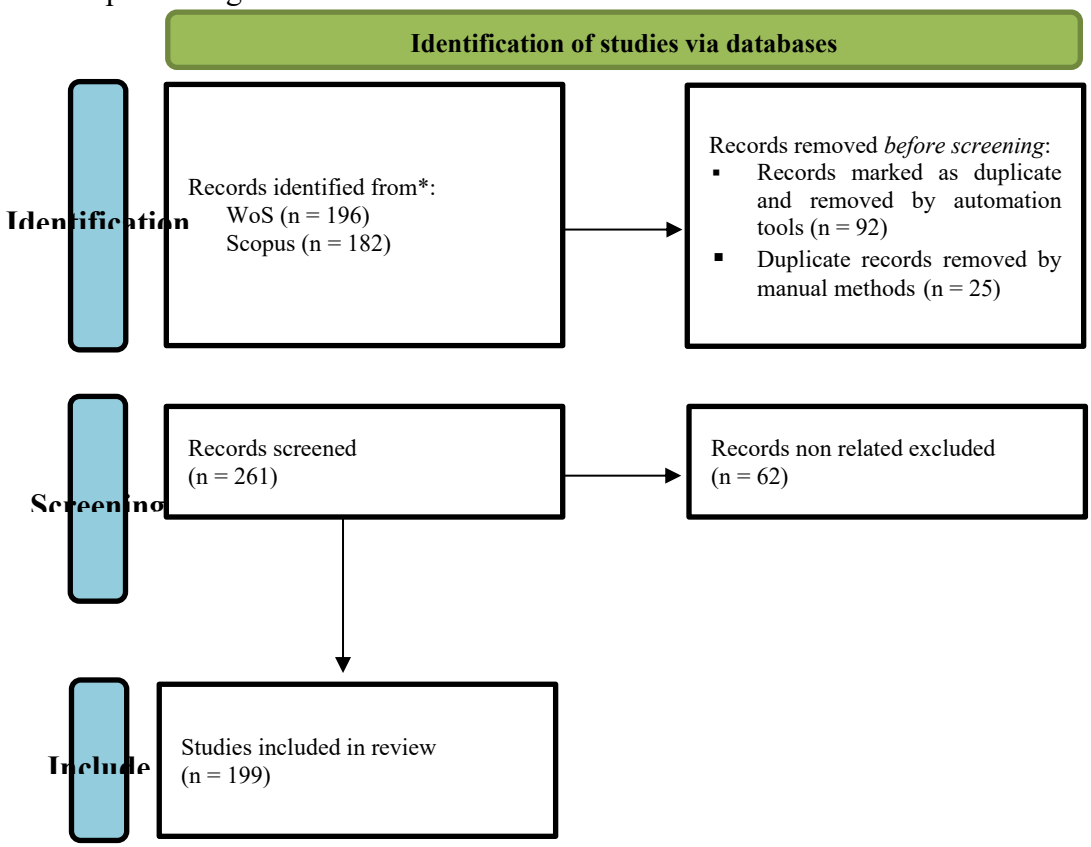

Figure 1. Flowchart of the document selection process (Page et al., 2021)

A descriptive bibliometric analysis was conducted. To determine whether the annual publications followed an exponential growth phase, according to DeSolla Price's law of exponential growth of science (Dobrov, Randolph, & Rauch, 1979; Price, 1976), the coefficient of determination (R2) adjusted to an exponential growth ratio was calculated to interpret this trend. The WoS Analyse Reports tool was utilized to descriptively analyze thematic categories with the most related publications, as well as the publishers and journals with the most papers in each category. Bradford's law of concentration of science (DeShazo, LaVallie, & Wolf, 2009; Goffman & Warren, 1969; Nash-Stewart, Kruesi, & Del Mar, 2012) was applied to highlight the most prolific journals and those with the highest number of citations. Lotka's law (Kushairi & Ahmi, 2021) was employed to identify authors with the highest number of publications, and the Hirsch index (h-index) was applied to these authors to determine those with the highest number of citations within the selected set of publications (Hirsch, 2005; Yie et al., 2021). To ascertain the most relevant articles, the Hirsch index (h-index) was used again, considering the h articles with h or more citations (Hirsch, 2005; Rodrigues-Santana et al., 2022). Finally, to determine the most relevant author keywords, Zipf's law was

applied to the set of author keywords from the publications analyzed (Zipf, 2013). The Biblioshiny tool from the Bibliometrix data package (Aria & Cuccurullo, 2017) was employed to generate visualization graphs of relationships between co-authors, keywords, countries, and articles, as well as to produce the world productivity map and productivity graphs of journals and institutions.

RESULTS

Annual publications trends

After applying the exclusion criteria, we obtained a total of 199 documents published between 1984 and 2024, which included 15 reviews, 180 articles, and 4 early access articles. There is no continuity in annual publications until 2006, the year in which we found at least one annual publication on the subject up to the present. Between 1984 and 2003, there is no annual continuity, with a total of 12 publications in that period. A preliminary filtering of our database with the search terms in titles and keywords allowed us to determine that 139 documents were related to parkour or freerunning, 48 to breakdance, and 12 to calisthenics or street workout.

We analyzed the trend followed by the annual publications between 2006 and 2022, inclusive, excluding the years in which there was no annual continuity and 2023, as the analysis has not concluded at the time of writing. As a result, we found that publications in this period follow an exponential growth trend with an adjusted percentage of 74.7% (R2) (Figure 2). At the time of the analysis, in 2023 and 2024, there are 18 publications related to the subject.

Figure 2. Annual publications trend on street-based acrobatic disciplines

Publications titles

We identified a total of 158 journals in which the documents were published, ranging from 1 to 6 publications each. The most prominent journals were determined using Bradford's law; however, due to the distribution of publications, only the core and Zone I could be identified. The core comprises 33.67% of the total number of documents and consists of 26 journals that have published between 5 and 2 documents each. The most prolific journal is the "International Journal of Sport Policy and Politics," published by Routledge Journals, Taylor & Francis LTD. It is located in the second quartile (Q2) of the category

"Hospitality, Leisure, Sport & Tourism - ESCI" and has a total of 6 documents. The next most prolific journals include the "European Journal of Sport Science" (Routledge Journals, Taylor & Francis LTD) and the "Journal of Physical Education and Sport," both with 4 publications. Additionally, there are 7 journals with 3 publications and 16 journals with 2 publications. Bradford's Zone I includes the remaining 132 journals, each with only one publication, accounting for 66.33% of the total number of publications. Table 1 presents the 8 journals included in the core with 3 or more publications and provides details such as publisher, impact factor, quartile, and open access percentage.

Table 1.
Journals with 3 or more publications

	Journals (Publishers)	Doc.	% Doc.	Cit.	JIF	Q.	% O.A.
Journals with 3 or more publications	International Journal of Sport Policy and Politics (Routledge Journals, Taylor & Francis LTD)	5	3.02%	183	*0.60	*Q2	25.76%
	European Journal of Sport Science (Taylor and Francis LTD)	4	2.01%	48	3.2	Q2	14.12%
	Journal of Physical Education and Sport	4	2.01%	8	n/a	n/a	n/a
	Qualitative Research In Sport, Exercise And Health (Routledge Journals, Taylor & Francis LTD)	3	1.51%	93	4.9	Q2	21.05%
	Theatre, Dance and Performance Training (Routledge Journals, Taylor & Francis LTD)	3	1.51%	35	3.2	Q2	14.12%
	Modern Italy (Cambridge Univ Press)	3	1.51%	28	0.5	Q3	52.78%
	Frontiers in Psychology (Frontiers Media SA)	3	1.51%	17	3.8	Q1	99.39%
	Sport in Society (Routledge Journals, Taylor & Francis LTD)	3	1.51%	15	1.4	Q3	14.59%
	International Journal of Morphology (Soc. Chilena Anatomía)	3	1.51%	5	0.5	Q4	3.72%
	Retos: Nuevas Tendencias en Educación Física Deporte y Recreación (FEADEF)	3	1.51%	0	1.3	Q3	24.78%

Doc. (Number of documents); Cit. (Number of citations); % Doc. (Percentage of documents); JIF (Journal impact factor); % O.A. (Percentage of open access); Q. (JIF Quartile); n.a. (not application). JIF or Q. with "*" are JCI (Journal Citation Indicator) and JCI Quartile.

Most prolific and influential co-authors

We identified a total of 417 researchers within the set of publications analyzed. Among them, 84.65% had only one paper (353 researchers), 10.07% had two publications (42 researchers), and 5.28% had 3 or more papers, with the maximum being 8 publications by one author. Applying Lotka's law, we determined that the most prolific authors would be the first 20 (√417), selecting 22 co-authors with 3 or more publications. The most prolific co-author was Signey Grosprêtre, with 8 papers, affiliated with Univ Bourgogne Franche Comte (France). This was followed by Nicola de Martini Ugolotti (Bournemouth University, England), Joseph Antony Stone, and Ben William Strafford (both from Sheffield Hallam University, England), each with 6 papers.

Figure 3 illustrates the 22 prolific co-authors and their interactions within the set of analyzed documents. The node size represents the level of interaction, while the thickness of the lines indicates the level of interconnection. Each color represents an author or group of collaborating authors. We identified 4 co-author groupings, with the largest being led by Signey Grosprêtre (highlighted in red). Another significant group (highlighted in orange) includes J. A. Stone, B. W. Strafford, K. Davids, and J. S.

North from Sheffield Hallam University, England, predominantly publishing papers related to parkour. Additionally, a group (highlighted in purple) comprising Y. Bai, Z. Yang, and M. T. Wei from the University of Melbourne (Australia) and Changshu Institute of Technology (China) focuses on breakdancing. Lastly, there is a pair of authors (highlighted in blue), M. D. Kauther and C. Wedemeyer from the University of Duisburg Essen (Germany), also contributing to breakdance-related papers.

To highlight which authors, within the 22 most prolific, are the most prominent, we checked which of these authors had a publication in the set of most cited documents (these are obtained by applying the h-index). We found that only 12 of the prolific authors meet this condition. This group is again headed by the authors mentioned in the most prolific section. Table 2 shows the 12 prominent authors, as well as their affiliations, location, number of papers and total citations.

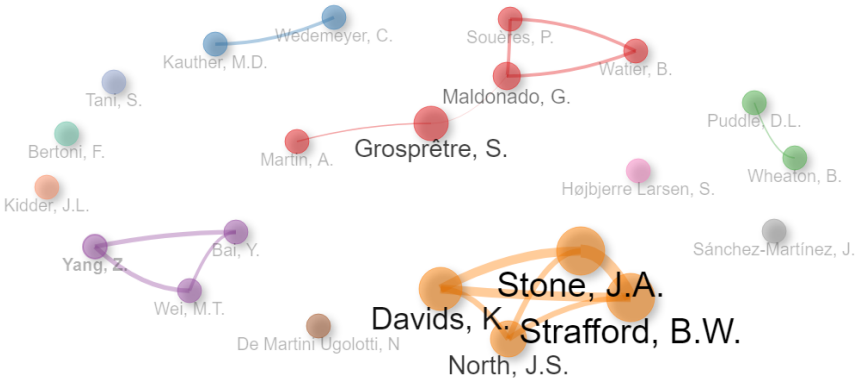

Figure 3. Chart with the prolific co-authors and their relationships. Bibliometrix: Analysis: Collaboration Network. Field: Authors. Network Layout: Kamada & Kawai. Clustering Algorithm: Walktrap. Normaization: Association. Number of nodes: 22. Repulsion force: 0.1. Remove isolated nodes: No. Min. number of edges: 1.

Table 2.
Most prominent co-authors

Co-authors	Affiliation / Countries-Regions	Documents	Citations
Grosprêtre, Signey	Univ Bourgogne Franche Comte / France	8	61
De Martini Ugolotti, Nicola	Bournemouth University / England	6	76
Stone, Joseph Antony	Sheffield Hallam University / England	6	53
Strafford, Ben William	Sheffield Hallam University / England	6	53
Davids, Keith	Sheffield Hallam University / England	5	52
Wheaton, Belinda	University of Waikato / New Zeland	4	163
Højbjerre Larsen, Signe	University of Southern Denmark / Denmark	4	63
Kidder, Jeffrey L.	Northern Illinois University / USA	3	128
Tani, Sirpa	University of Helsinki / Finland	3	70
Kauther, Max Daniel	University of Duisburg Essen / Germany	3	64
Wedemeyer, Christian	University of Duisburg Essen / Germany	3	64
Puddle, Damien L.	University of Waikato / New Zeland	3	56

Countries/Regions

We found a total of 41 countries/regions to which the co-authors of

all the documents in the analysis belong. According to the number of documents, we can highlight France (27 documents) as the most productive country, followed by the USA (26 documents), Germany (22 documents), the United Kingdom (21 documents), and China (13 documents). According to the number of citations, the United Kingdom stands out in first place with 522 total citations, the USA again in second place (345 citations), followed by France (158 citations), Germany (81 citations), and, in fifth place, Finland, with 5 documents and 73 citations.

Figure 4 represents the collaboration network between countries/regions, showing the interactions between them. The size of the node represents the level of collaboration, and the thickness of the connections indicates the amount of interactions. We can highlight China as the most collaborative country, which is grouped with Thailand, Australia, Singapore, and Canada (highlighted in red). The USA presents connections with Finland and Chile (highlighted in blue). Finally, we find connections between Poland and Russia (highlighted in green). Figure 5 shows a map of the world in which the volume of publications is highlighted in shades of blue; the darker the shade of blue, the greater the number of publications.

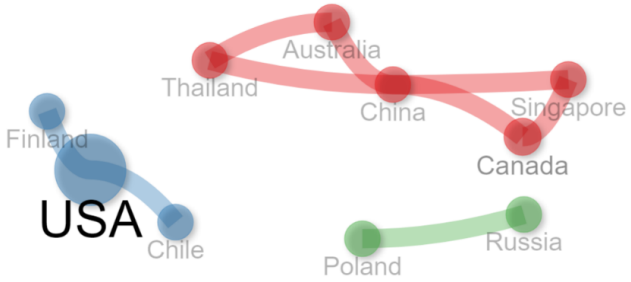

Figure 4. Collaboration network between countries/regions. Bibliometrix: Analysis: Collaboration Network. Field: Countries. Network Layout: Automatic layout. Clustering Algorithm: Walktrap. Normaization: Association. Number of nodes: 41. Repulsion force: 0.1. Remove isolated nodes: Yes. Min. number of edges: 1.

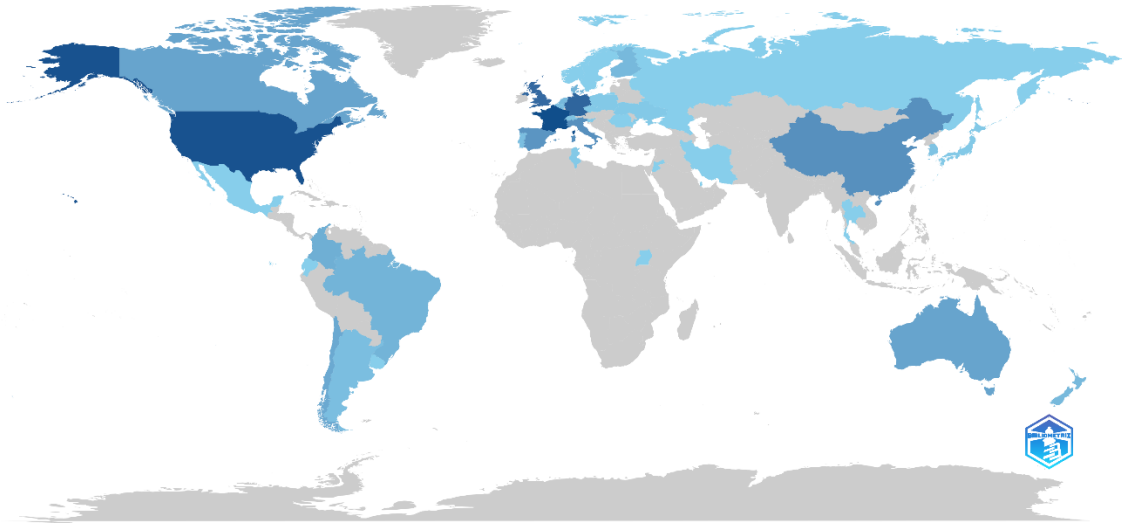

Figure 5. Country scientific production

Author keywords

The total number of keywords used by the authors in the documents selected for our analysis is 553. Applying Zipf's law, it

was determined that the most relevant ones should have a frequency of 23 or fewer. We found 20 words with 5 or more occurrences and 28 words with 4 or more occurrences. The first 20 were selected as the most relevant keywords for the authors. The author keywords were reviewed and corrected or collected in thesauri of synonyms. Two of the three sport modalities that were searched, "parkour" (73 occurrences) and "breakdancing" (24 occurrences), stand out in first place; the terms "free running" (8 occurrences) and "street workout" (5 occurrences), despite having been used in the search vector, are not at the top of the list. The five words with the highest number of occurrences that are not part of the search vector are "injury" (12 occurrences), "hip hop" (11 occurrences), and "lifestyle sports" (11 occurrences).

Figure 6 shows the most relevant keywords and their connections. The size of each node represents the number of occurrences, the thickness of the line indicates the frequency with which they appear together, and the proximity of one node to another represents the relationship between them. We can distinguish three groupings, each related to one of the sports modalities of the analysis. Highlighted in blue is the cluster headed by the term "parkour" along with nine other keywords. Highlighted in red is the cluster headed by the term "breakdance," together with seven directly related terms. Highlighted in green is the term "street workout," which appears more isolated. Figure 7 represents the cumulative frequency of appearance of the 10 most relevant keywords over time, showing that in 2007 the term "parkour" began to be used as a keyword. The term "breakdance" began to be used in 2008, a year after parkour, and it shows much less pronounced growth compared to parkour.

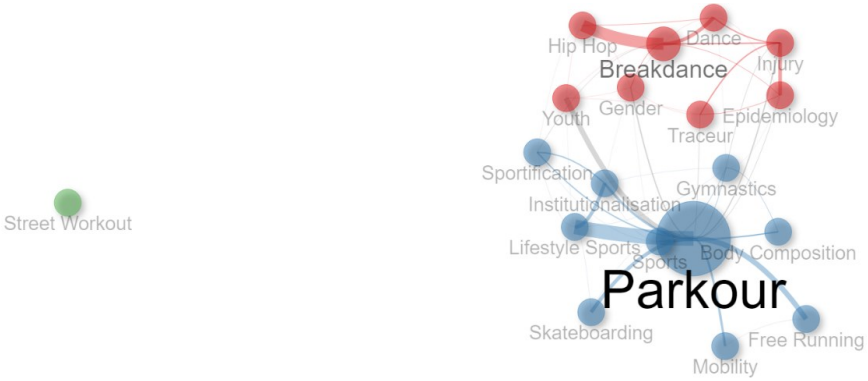

Figure 6. Most important author keywords and their connections. Bibliometrix: Analysis: Co-Ocurrence Network. Field: Author's Keyword. Network Layout: Automatic layout. Clustering Algorithm: Walktrap. Normaization: Association. Number of nodes: 20. Repulsion force: 0.1. Remove isolated nodes: No. Min. number of edges: 1

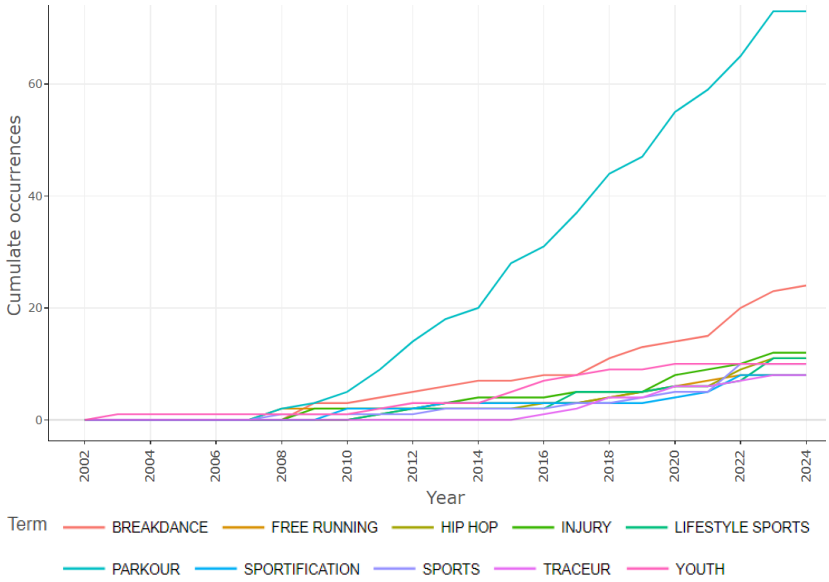

Figure 7. Most prominent author keywords and their cumulative frequency over time. Bibliometrix: Analysis: Word Dynamics. Field: Author's Keyword. Ocurrences: Cumulate. Number of words: 10.

Documents

We can highlight as the most relevant articles in our subject matter the first 26 publications with at least 27 citations (Table 3), applying the h-index. The most cited article is "Playing With Fear: Parkour And The Mobility Of Emotion" by Saville (2008), with a total of 156 citations, published in "Social And Cultural Geography." This paper explores the emotions involved in parkour, highlighting the playfulness and fear that practitioners experience in engaging with different places.

The next article with the most citations is entitled "Parkour, Anarcho-Environmentalism, and Poiesis" published by Atkinson (2009) in the journal "Journal Of Sport And Social Issues," with a total of 129 citations. This article seeks to analyze how parkour can be seen as a form of resistance against technology and urban structure and how it can be used to rediscover the city in a different way. The breakdance-related article with the highest number of citations is "Breakdance Injuries And Overuse Syndromes In Amateurs And Professionals" by Kauther et al. (2009), with 36 citations, dealing with breakdance injuries at different levels. Figure 8 represents the most cited articles and their interrelationships.

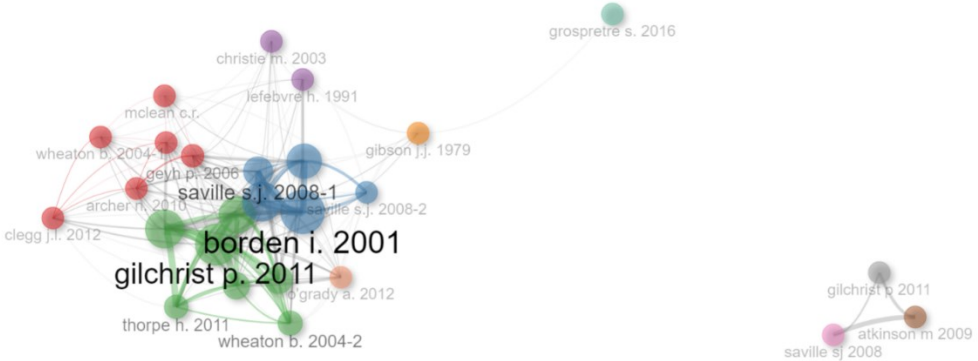

Figure 8. Graph with the most cited articles and their interrelationships. Bibliometrix: Analysis: Co-citation Network. Field: Papers. Network Layout: Kamada & Kawai. Clustering Algorithm: Walktrap. Number of nodes: 26. Repulsion force: 0. Remove isolated nodes: Yes. Min. number of edges: 2.

Table 3.
Documents

Title. Main author (Year of publication)	Journal ISO Abbreviation	Cites
Playing with Fear: Parkour and the Mobility of Emotion. Saville (2008)	Soc. Cult. Geogr.	156
Parkour, Anarcho-Environmentalism, and Poiesis. Atkinson (2009)	J. Sports Soc. Issues	129
Lifestyle Sport, Public Policy and Youth Engagement: Examining the Emergence of Parkour. Gilchrist &Weaton (2011)	Int. J. Sport Policy	124
Parkour The City the Event. Mould (2009)	Environ. Plann. D Soc. Space	78
Parkour The Affective Appropriation of Urban Space and the Realvirtual Dialectic. Kidder (2012)	City Commun.	68
Breakdance Injuries and Overuse Syndromes in Amateurs and Professionals. Kauther et al. (2009)	Am. J. Sports Med.	57
When Walls are No Longer Barriers Perception of Wall Height in Parkour. Taylor et al. (201)	Perception	52
Youth Action Sports and Political Agency in the Middle East Lessons from a Grassroots Parkour Group in Gaza. Thorpe & Ahmad (2015)	Int. Rev. Sociol. Sport	52
Terrain Runner Control Parameterization Composition and Planning for Highly Dynamic Motions. Liu et al. (2012)	Acm Trans. Graph.	50
Parkour Creating Loose Spaces. Ameel & Tani (2012)	Geogr. Ann. Ser. B Hum. Geogr.	48
An Existential Phenomenological Examination of Parkour and Freerunning. Clegg & Butryn (2012)	Qual. Res. Sport Exerc. Health	44
Ground Reaction Forces and Loading Rates Associated with Parkour and Traditional Drop Landing Techniques. Puddle & Maulder (2013)	J. Sports Sci. Med.	41
Climbing Walls Making Bridges Children of Immigrants Identity Negotiations Through Capoeira and Parkour in Turin. De Martini Ugolotti (2015)	Leis. Stud.	39
Parkour as Acrobatics An Existential Phenomenological Study of Movement in Parkour. Aggerholm & Højbjerre (2017)	Qual. Res. Sport Exerc. Health	37
Injury Incidence in Hip Hop Dance. Ojofeitimi et al. (2012)	Scand. J. Med. Sci. Sports	35
Personality Self-efficacy and Risk-taking in Parkour Freerunning. Merritt & Tharp (2013)	Psychol. Sport Exerc.	33
From Break Dancing to Heavy Metal Navajo Youth Resistance and Identity. Deyhle (1998)	Youth Soc.	33
Parkour Masculinity and the City. Kidder (2013)	Sociol. Sport J.	32
Break Dancing and Breaking out Anglos Utes and Navajos in a Border Reservation Highschool. Deyhle (1986)	Anthropol. Educ. Q.	29
Performance Characteristics of Parkour Practitioners Who Are the Traceurs. Grosprêtre & Lepers (2016)	Eur. J. Sport Sci.	28
Break Dance Significantly Increases Static Balance in 9 Year-Old Soccer Players. Ricotti & Ravaschio (2011)	Gait Posture	28
Parkour A New Extreme Sport and A Case Study. Miller &Demoiny (2008)	J. Foot Ankle Surg.	28
Parkour Adventure Risk and Safety in the Urban Environment. Kidder (2013)	Qual. Sociol.	28
Musculoskeletal Injuries in Breakdancers. Cho et al. (2009)	Injury-Int. J. Care Inj.	28
Parkour as a Donor Sport for Athletic Development in Youth Team Sports Insights Through an Ecological Dynamics Lens. Strafford et al. (2018)	Sports Med. - Open	27
The Aesthetics of Urban Movement Habits Mobility and Resistance. Sharpe (2013)	Geogr. Res.	27

DISCUSSION

Regarding acrobatic sports with street origins, this research is pioneering, as no similar studies were found. A total of 199 documents published between 1984 and 2024 were analyzed. Although no annual continuity was found in the publications until 2006, the trend from then onwards shows exponential growth, demonstrating scientific community interest in these types of sports. This study identifies the temporal evolution of publications related to the subject, the most prolific and cited journals, the most productive and prominent authors, the most relevant articles, and the keywords most used by researchers, all following traditional laws of bibliometrics (Goffman & Warren, 1969; Kushairi & Ahmi, 2021; Nash-Stewart et al., 2012; Price, 1976; Zipf, 2013)..

The oldest paper is entitled "Injuries from Break Dancing" (Norman & Grodin, 1984), focusing, as its title indicates, on breakdancing injuries. Reviewing the oldest papers, we find that the first 12 are related to breakdancing. Breakdancing originated in the Bronx (New York) in the 1970s (International Olympic Committee, n.d.), but its popularity increased significantly in 1983-1984 due to its portrayal in movies such as Flashdance (1983), Breakin' (1984), and Breakin' 2: Electric Boogaloo (1985) (‘Break dance’, 2023). The rise in popularity during these years coincides with the first related research, suggesting a possible connection between the two. Breakdancing is set to be included in the 2024 Olympic Games (International Olympic Committee, n.d.), which may again lead to an increase in related publications.

The first paper related to parkour dates from 2006, entitled "Paediatric Fractures Sustained in Parkour (Free Running)" (McLean, Houshian, & Pike, 2006). The article analyzes two cases of pediatric fractures in untrained individuals practicing parkour without protective equipment, highlighting the risk of upper extremity injuries in children due to falls, with the distal radius being the most frequently fractured part of the immature skeleton. From this date onwards, there are more publications related to parkour than to breakdancing. Parkour originated in France in the late 1980s but did not gain widespread popularity until the late 1990s and early 2000s, spurred by movies like Yamakasi (2001) and District 13 (2004). David Belle, a member of the first parkour group, further increased the sport's visibility by sharing his skills on YouTube (LW, 2023). The timing of parkour's television exposure aligns with the burgeoning scientific interest, indicating a potential relationship.

The first document related to freestyle calisthenics or street workout is from 2017, with two documents published that year: "Morphological Characteristics of Street Workout Practitioners" (Sanchez-Martinez, Plaza, Araneda, Sanchez, & Almagia, 2017) and "Assessment of Physical Fitness Indicators in Students Practicing Powerlifting and Street Workout" (Kharisov, Nenasheva, Aminov, Cieslicka, & Mushketa, 2017). Both papers focus on the morphological profile and physical fitness of practitioners. This sport has a more diffuse origin, heavily influenced by social networks, and has gradually incorporated new elements from artistic gymnastics and parkour into traditional calisthenics (‘Entrenamiento callejero’, 2022). The Spanish Federation of Street Workout and Calisthenics was founded in February 2015, the same year the first official competition took place (‘Entrenamiento callejero’, 2022). From this point, the competition

modalities became more clearly structured, with freestyle calisthenics being referred to as street workout or freestyle modality (‘Entrenamiento callejero’, 2022). Given its recent creation, it is logical that the first studies on this sport appeared in 2017.

The analysis of the most productive journals did not conform to Bradford's theoretical model, revealing only the core and zone 1. The core was composed of 26 journals with a total number of publications ranging between 6 and 2. This large core indicates that there are no specific journals exclusively focused on the analyzed subject matter, with publications being distributed primarily in journals related to physical activity and sport. It may also suggest that analyzing three different sports has resulted in a mixed distribution of journals, showing a more confusing structure.

The most prolific journal was "International Journal of Sport Policy and Politics" from Routledge Journals, Taylor & Francis LTD, with 6 publications. This journal aims to publish papers addressing all aspects of general politics and sport policy. Notable from this journal is the article "Lifestyle Sport, Public Policy and Youth Engagement: Examining the Emergence of Parkour" (Gilchrist & Wheaton, 2011), which has 124 citations. The other five papers published in this journal also relate to aspects of institutionalization or the parkour lifestyle.

The next journals with the highest number of publications are "European Journal of Sport Science" (Taylor and Francis LTD) and "Journal of Physical Education and Sport", each with 4 papers, almost all related to parkour. The only paper not covering parkour published in the "Journal of Physical Education and Sport" is entitled "Street Workout Is the New Gymnastics - Strength Development in a Very Short School-Based Program" (Schlegel, Sedláková, & Křehký, 2022), which relates to street workout.

Of the prolific journals, the only ones presenting papers related to sports other than parkour are "Frontiers in Psychology" (Frontiers Media SA) and "Retos" (FEADEF), which have papers related to breakdancing; "Sport in Society" (Routledge Journals, Taylor & Francis LTD), which has a paper related to street workout; and "International Journal of Morphology" (Soc. Chilena Anatomía), which has a paper related to breakdancing and two related to street workout.

Regarding the scientific production of the authors, S. Grosprêtre stands out with 8 articles. Although he does not belong to a specific research group, he collaborates with other authors, such as A. Martin and the research group of G. Maldonado. His publications are related to parkour, with his most cited article being "Performance Characteristics Of Parkour Practitioners Who Are The Traceurs" (Grosprêtre & Lepers, 2016), which is included among the set of relevant articles.

The next most prolific authors, each with 6 papers, are N. de Martini Ugolotti and B. W. Strafford, along with J. A. Stone. N. de Martini Ugolotti generally approaches the subject from a social perspective. B. W. Strafford and J. A. Stone, who work together with K. Davids and J. S. North, focus on parkour from a sporting perspective. All these authors are part of the set of prominent authors.

The prominent authors with the highest number of citations are B. Wheaton, with 4 papers and 163 citations, and J. L. Kidder, with 128 citations and 3 papers. Belinda Wheaton collaborates with D. L. Puddle, who is also a prominent author with 3 papers and 56 citations. Both authors have co-

authored two papers related to parkour (Puddle & Wheaton, 2023; Puddle, Wheaton, & Thorpe, 2019). B. Wheaton's most cited paper is "Lifestyle Sport Public Policy and Youth Engagement: Examining the Emergence of Parkour" (Gilchrist & Wheaton, 2011), published in the "International Journal of Sport Policy". J. L. Kidder's three articles, all related to parkour, are highlighted as relevant (Kidder, 2012, 2013a, 2013b).

The featured authors with the highest number of citations and who also publish on breakdancing are M. D. Kauther and C. Wedemeyer, with 3 articles and 64 citations. All three articles focus on injuries in the discipline of breakdancing, and they are co-authored with less prominent authors. Their most relevant article is "Breakdance Injuries and Overuse Syndromes in Amateurs and Professionals" (Kauther et al., 2009), with 57 citations.

The author with the most papers related to street workout is Javier Sanchez-Martinez, with 4 papers and 9 citations, although he is not included in the set of prominent authors. His most cited paper is "Morphological Characteristics of Street Workout Practitioners" (Sanchez-Martinez et al., 2017). However, the most cited paper related to street workout is "The Comparative Analysis of Morphological and Functional Indicators of Arm Wrestling and Street Workout Athletes" (Podrihalo et al., 2021), which compares the physical condition of arm wrestlers with that of street workout practitioners.

The most cited paper related to parkour is the one at the top of Table 3, entitled "Playing With Fear: Parkour and the Mobility of Emotion" (Saville, 2008). As for breakdancing, the most cited paper is in sixth place and is entitled "Breakdance Injuries and Overuse Syndromes in Amateurs and Professionals" (Kauther et al., 2009).

Regarding the number of publications presented by each country, it is interesting to note that France ranks first with 27 documents and 158 citations, the country of origin of parkour. In second place is the USA, with 26 documents and 345 citations, the country of origin of breakdancing. In bibliometric analyses, the USA usually accumulates the greatest number of documents, so it is worth noting the influence that parkour has had on the scientific production of its country of origin.

Looking at the distribution of the author keywords (Figure 7), we observe three groups, each related to one of the sports analyzed. The group related to street workout presents a single keyword, namely the term "street workout". This can be justified due to the low number of publications related to the sport, all these publications share this term but the rest of the related keywords do not accumulate 5 or more appearances, so they do not appear in the graph.

The term "breakdance" appears accompanied by several terms that describe various aspects of this sport, such as "hip hop" and "dance"; and by other terms that are related to the population that is usually practicing or perspectives that have been interesting or controversial, such as "youth" or "epidemiology". The term "traceur" also appears within this grouping, this is due to the fact that although it is not directly related to the term "breakdance", it is directly related to the terms "gender" and "injury". Many articles on parkour, as well as on breakdance, address the issue of injuries or the use of these sports to combat or vindicate inequality.

The term "parkour", on the other hand, is accompanied by terms that refer to the

attempt to turn it into a regulated sport, such as "sportification" and "institutionalisation"; there are also terms that refer to its acrobatic nature and its fundamental idea, which is mobility, such as "gymnastics" and "mobility". Parkour for its practitioners is usually more than a sport, it is a lifestyle, which is reflected in the term "lifestyle sports".

Finally, it is worth mentioning that there are two sports that tend to be closely linked to this discipline, these are "skateboarding" and "free running", the latter being a modality derived from parkour.

This study serves as a valuable tool for authors, research groups, and publishers to understand the current trends in scientific production within the field of street acrobatics. By analyzing the three main disciplines collectively and occasionally individually, it provides insight into the temporal evolution and various branches of research within each discipline. This enables individuals interested in these sports to gain a comprehensive understanding of their development and research directions.

Identifying key authors in the field can facilitate the formation of productive research groups, while leveraging the information presented in this study can enhance the development of research projects with strong connections to seminal works. The increasing trend in this thematic area suggests that future research, if approached correctly, has the potential to yield publications with significant readership and impact.

However, it's important to acknowledge some limitations in this study. We recognize the possibility of publication bias as we only analyzed articles from WoS Core and Scopus databases, which, although comprehensive and prestigious, may not cover all relevant publications. Some articles related to the subject may have been published in sources of lower impact or not indexed in these databases. Future research could address these limitations by conducting individual analyses for each discipline and expanding the scope to include additional databases.

Annual publications related to street acrobatics, specifically parkour, breakdance, and calisthenics, have exhibited an exponential growth trend over the past 18 years. Parkour leads with the highest number of related articles (139 papers), followed by breakdance (48 papers), and finally, freestyle calisthenics or street workout (12 papers). Despite breakdancing having an older origin than parkour, the latter surpasses breakdancing in the number of publications. The emergence of parkour and breakdancing in movies and television significantly influenced the popularization of these sports and consequently, the development of related scientific production. There appears to be a temporal relationship between their introduction to television and the commencement of scientific publications. Street workout, being a recently established sport, does not yet exhibit a similar evolution to other sports, although its popularity has also been greatly influenced by social networks.

The most prolific journal on the subject is the "International Journal of Sport Policy and Politics" from "Routledge Journals, Taylor & Francis LTD", featuring predominantly parkour publications, like the majority within the core. Other journals such as "Frontiers in Psychology", "Retos", and "International Journal of Morphology" present publications related to breakdancing, while "Journal of Physical Education and Sport", "Sport in Society", and again, "International Journal of Morphology"

feature publications related to street workout.

The most relevant papers in each sport are "The Comparative Analysis of Morphological and Functional Indicators of Arm Wrestling and Street Workout Athletes" (Podrihalo et al., 2021) in street workout; "Playing with Fear: Parkour and the Mobility of Emotion" (Saville, 2008) in parkour; and "Breakdance Injuries and Overuse Syndromes in Amateurs and Professionals" (Kauther et al., 2009) in breakdance.

The most prominent author in the field of parkour is Signey Grosprêtre, with 8 papers; the most prominent authors presenting papers related to breakdance are Max Daniel Kauther and Christian Wedemeyer, with 3 papers each; and finally, the most prolific author publishing on street workout is Javier Sanchez-Martinez, with 4 papers.

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SHORT HISTORICAL NOTES XXX

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

Ph.D. Anton Gajdoš born on 1.6.1940 in Dubriniči (today Ukraine) lives most of his life in Bratislava (ex TCH, nowadays SVK). He comes from gymnastics family (his brother Pavel have world championship medals) and he devoted his life to gymnastics. His last achievement is establishment of Narodna encyklopedia športu Slovenska (www.sportency.sk). Among his passion is collecting photos and signatures of gymnasts. As we tend to forget old champions and important gymnasts, judges and coaches, we decided to publish part of his archive under title Short historical notes. All information on these pages is from Anton's archives and collected through years.

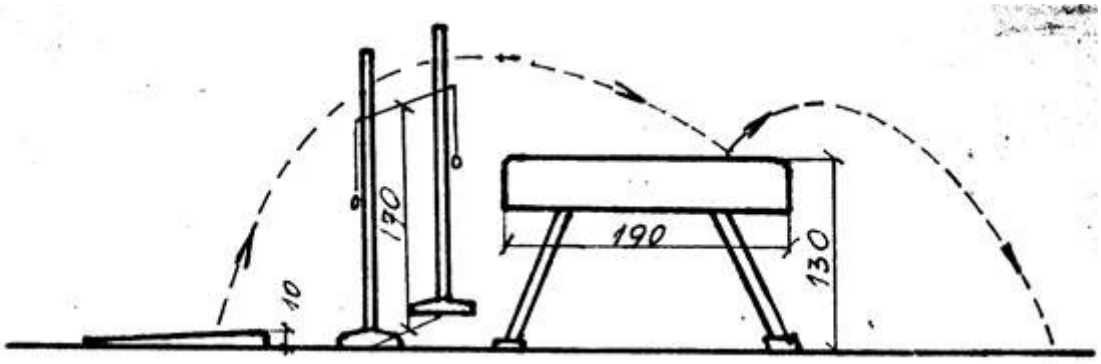
8th Olympic Games in Paris

Artistic Gymnastics competition was for men only. Nine countries participated: USA, Finland, United Kingdom, Italy, Switzerland, Czechoslovakia, France, Luxemburg and Kingdom of Yugoslavia with 72 gymnasts.

On the first day gymnasts competed on horizontal bar, parallel bars, side horse vault and on second da on rings, pommel horse, long horse vault and rope climbing. On vault and rope climbing only one attempt was allowed, on other apparatus compulsory and optional exercises were required.

On **vault and rope climbing** maximum score was **10 points** and on **other apparatus** was **11 point**s (10 for exercise presentation and 1 point for approaching and leaving apparatus). **Rope climbing** had following scoring:

Time	Score
Less than 9.00 s	**10**
9.20	9
9.40	8
9.60	7
9.80	6
10.20	5
10.60	4
11.00	3
11.60	2
11.80	1
12.00	0



Long horse vault had special rules. In front of horse it was placed a stick at certain height and according to the height, maximum score was defined: 170 cm for 10 points, and than for each 5 cm less one point less. Gymnasts had to perform split jump. (Picture from: Vazzaz J., Gregorka B.: Razvoj telovadnega orodja na Slovenskem (1984), Begunje: Elan (1984))

Quite **many gymnasts** performed so well, they **scored maximum score - perfect 10 or perfect 11.**

With perfect 11 were evaluated on apparatus for compulsory or optional exercise:

On parallel bars for optional exercise **Giorgio Zampori** , Italy

On rings for optional exercise **Leon Štukelj**, Slovenia (Yugoslavia)

With perfect 10 were evaluated:

On side horse vault **Albert Seguin**, France

On rope climbing 22 gymnasts scored 10 point,, the fastest was

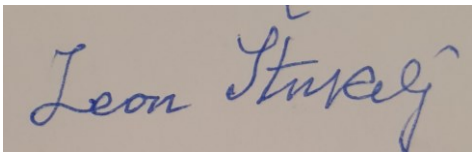
Karel Šupčik from Czechoslovakia with result of **7.20s**

Other gymnasts with 10 points were: Vacha, Pražak, Morkovsky (Czechoslovakia), Seguin, Delsarte, Gounot, Hermann (France), Guttinger, Grieder (Switzerland), Žilič, Štukelj, Porenta (Yugoslavia), Križ, Pearson, Safanada, Wanderer (USA) and Cambiaso, Lertora, Lucchetti, Mandrini, Martino (Italy).

Results

Teams: 1. Italy, 2. France, 3. Switzerland
All around: 1. Štukelj (SLO, YUG), 2. Pražak (TCH), 3. Šupčik (TCH)
Horizontal bar: 1. Štukelj (SLO, YUG), 2. Gutweniger (SUI), 3. Higelin (FRA)
Parallel bars: 1. Guttinger (SUI), 2. Pražak (TCH), 3. Zampori (ITA)
Rings: 1. Martino (ITA), 2. Pražak (TCH), 3. Vacha (TCH)
Pommel horse: 1. Wilhelm (SUI), 2. Pražak (TCH), 3. Vacha (TCH)
Long horse vault: 1. Križ (USA), 2. Koutny (TCH), 3. Morkovsky (TCH)
Side horse vault: 1. Seguin (FRA), 2. Counot (FRA), 3. Gangloff (FRA)
Rope climbing: 1. Šupčik (TCH), 2. Seguin (FRA), 3. Vacha (TCH)

As a surprise Leon Štukelj (Slovenia/Yugoslavia) won all around. His performance specially on long horse vault was decisive as Leon Štukelj was only 1.60 meter tall. He jumped for 10 points vault and rised his body center of gravity over 2 meters, what mean he had extreme athletic abilities.



Slovenski izvlečki / Slovene Abstracts

Thomas Heinen, Jannis Frackmann, Alina Müller in Vanessa Zöllner

UPRAVLJANJE GIBANJA PRI SESKOKIH Z GREDI

Pri orodni telovadbi velja, da je zgradba orodja bistveno za upravljanju uspešnosti telovadnih veščin, kjer sta pomembna zaznavanje in upravljanje. Postavlja se vprašanje, kako se takšno upravljalno posplošujejo znotraj telovadnih veščin s podobnim gibalnim ciljem, a drugačno strukturo. Zato je bila ta raziskava zasnovana za razčlenitev, kako določena omejitev okolja (prostor, ki je na voljo na gredi) uravnava uspešnost telovadcev v veščinah s podobnim gibalnim ciljem, vendar drugačno gibalno strukturo. Telovadke so izvedle premet vstran z obratom na not in premet naprej kot seskok iz gredi v dveh pogojih (osnovna postavitev v primerjavi z zmanjšanim razpoložljivim prostorom). Pri telovadkah so se pokazale razlike v položaju stopal med poskusnima pogojema. Pri obeh prvinah se je najpomembnejši del upravljanja zgodil med začetnim položajem in prvim korakom, majhen del pa med prvim korakom in postavitvijo rok. Za premet vstran nazaj se je zgodila še ena majhna uravnava med postavitvijo druge roke in doskokom na blazino; praktično ni bilo nobenega upraljnaja med postavitvijo rok in doskokom na blazini v premetu naprej. Zaključeno je, da je za telovadke prilagajanje različnim omejitvam od poskusa do poskusa bistvena veščina. Uvedba teh omejitev v praksi lahko pomaga razviti širok nabor upravljalnih vzorcev.

Ključne besede: povezava zaznavanje-dejanje, omejitve okolja, premet vstran, premet naprej.

Helmy Firmansyah, Rion Hendrianto, Jajat Darajat Kusumah Negara in Tri Martini

RAVNOTEŽJE V ŠPORTU: KAKO SPOZNAVNE VEŠČINE PRISPEVAJO K BOLJŠIM TELOVADNIM USPEHOM

Poklicni vaditelji in športniki pogosto zanemarjajo pomen spoznavnih veščin, vendar so le-te nedvomno med ključnimi za izboljšanje uspešnosti športnikov. Ta raziskava želi raziskati vlogo spoznavnih veščin pri uspešnosti telovadcev z uporabo korelacijske metode. V raziskavo je bilo vključenih sedemintrideset mladih telovadcev (povprečna starost 18,64 ± 0,83 let), ki so se redno udeleževali tekmovanj in se nanje pripravljali. Raziskovalni podatki so bili zbrani iz meritev spoznavnih sposobnosti in telovadne uspešnosti, ki jih je pregledala skupina strokovnjakov. Ugotovitve te raziskave kažejo, da so boljše spoznavne sposobnosti pripeljale do boljše telovadne uspešnosti s poudarkom na pomembnosti pozornosti, zbranosti, spomina, vidno-prostorskih, jezikovnih in izvršilnih delovanj. Nadaljnje raziskave v daljšem časovnem obdobju bi lahko preučile razvoj spoznavnih sposobnosti športnikov in se osredotočile na izvajanje vadbe spoznavanja za izboljšanje telovadne uspešnosti.

Ključne besede: spoznavne veščine, telovadni nastop, mladi telovadci.

Ana Kašček Bučinel, Matej Supej, Nicola Petrone, Ivan Čuk

POMEN SKLADNOSTI TELESA ZA VZPOSTAVITEV RAVNOTEŽJA V STOJI PO SKOKU

Namen raziskave je bil ugotoviti, ali skladnost telesa vpliva na vzpostavitev ravnotežja po skoku v globino v stoji na nogah. V raziskavi je sodelovalo 32 zdravih športnikov z izkušnjami v orodni telovadbi. Udeleženci so bili povprečno stari 19,8 ± 1,4 leta, visoki 182,9 ± 6,8 cm in težki 79,1 ± 8,1 kg. Telesne značilnosti so bile ocenjene z merjenjem razlik med levo in desno stranjo v obsegu podlakti, obsegu nadlahti, obsegu meč, obsegu stegen, višini ramen, pusti masi nog in pusti masi rok. Rezultat stoječega ravnotežja je bil izračunan na podlagi faktorskih rezultatov, pridobljenih iz devetih meritev, izvedenih v 30 sekundah po skoku s 25 cm visoke podlage. Te meritve so vključevale tri za normalno stojo, tri za stojo brez vidne zaznave in tri za stojo brez slušne zaznave. Podatki so bili zbrani s pomočjo sistema pritiskovnih stopalnih vložkov in z merjenjem razlike v reakcijski sili na tla med levo in desno nogo. Stopenjska regresijska analiza je pokazala, da je 27 % razlik v obremenitvi nog mogoče razložiti z razlikami v telesnih značilnostih med levo in desno stranjo z dvema pomembnima napovedovalcema: razliko v višini ramen, ki pojasnjuje 16 % spremenljivosti, in razlike v pusti masi rok, ki pojasnjuje 11 %. Obe spremenljivki sta pokazali negativno povezavo z izvedbo skoka iz stoje. Neravnovesja v telesni skladnosti povečajo dolgoročno tveganje za enkratne ali dolgotrajne poškodbe.

Ključne besede: 3D čitalec, ravnotežje, somernost telesa, In Body, skok, tlačni vložek.

Natália Fontes Alves Ambrósio, Guilherme Menezes lage, Lucas Eduardo Antunes Bicalho, Crislaine Rangel Couto, Ivana Montandon Soares Aleixo, Tércio apolinário-souza

RAZMERJE MED ZMOGLJIVOSTJO V MOČI IN GIBALNO ZMOGLJIVOSTJO V STOJI NA ROKAH: MODEL STROJNEGA UČENJA

Raziskava je preučevala razmerje med zmogljivostjo moči in gibalno zmogljivostjo v stoji na rokah. Hipoteza je določala pozitivno razmerje med gibalno zmogljivostjo in stopnjami moči. V raziskavi je sodelovalo 32 študentov, 16 študentk in 16 moških (24,03 ± 4,74 let). Stoja na rokah je bila ocenjena s popolno napako treh kotov, ki jih je ustvaril model (video) in treh kotov, ki jih je ustvaril izvajalec. Izvedli so štiri teste moči: eksplozivna sila, največja moč desnega prijema, največja moč levega prijema in sila upora. Model strojnega učenja je vadil z uporabo 10 poskusov in je navzkrižno veljaven, izveden pa je bil tudi linearna regresija z gibalno zmogljivostjo (nesporna napaka) in meritvami moči (eksplozivna sila, največja sila na desni strani, največja sila na levi strani in sila upora). Rezultati so pokazali, da je model strojnega učenja pokazal nizko razmerje med zmogljivostjo moči in gibalno zmogljivostjo. Poleg tega ni bilo ugotovljeno, ali je gibalna zmogljivost povezana z močjo. Rezultati lahko kažejo, da določene zmogljivosti in sodelovanje dejavnikov, kot so posebnost naloge, okolje in posameznikove lastnosti, vplivajo na gibalno zmogljivost.

Ključne besede: šport, vadba, gibalne naloge, gibalni nadzor, gibalno obnašanje.

Letícia Bartholomeu de Queiroz Lima, Marco Antonio Coelho Bortoleto, Mauricio Santos Oliveira in Laurita Marconi Schiavon

ŽENSKA ORODNA TELOVADBA V BRAZILIJI: NJENE POTI OD 1966 DO 2021

Brazilska moška in ženska orodna telovadba je bila v središču pozornosti zaradi rezultatov nekaterih izjemnih športnikov na najpomembnejših mednarodnih tekmovanjih v zadnjih 20 letih. Vendar pa razvoj tega športa v narodnem smislu ne odraža teh dosežkov. Ta članek izvaja kritično razčlenitev ženske orodne telovadbe v Braziliji, pregleduje pot glavnih telovadk in njihove dosežke na svetovnih prvenstvih in olimpijskih igrah od leta 1966 do 2021 ter pomembna dejstva v tem zgodovinskem obdobju. Odličja na velikih tekmovanjih se osvajajo od leta 2001, s postopno in nestabilno rastjo pa se Brazilija uvršča med najuglednejše države. Kljub temu podatki kažejo, da so dosežki temeljili na zgoščenem vlaganju v izbrane odlične telovadce, predvsem v olimpijsko vrsto ob podpori že uveljavljenih društev. Razvoj je še vedno usmerjen in osredotočen na nekaj društev, brez trajnega povečanja števila društev in telovadcev. V tem scenariju obstaja potreba po dolgoročnem načrtu, ki lahko vzdržuje razvoj narodnega okolja (društev, krajevnih tekmovanj, pokrajinskih zvez) v vseh starostnih kategorijah in v povezavi s telovadnimi vrstami.

Ključne besede: orodna telovadba, Brazilija, ženske, zgodovina.

Hayk Gasparyan

RAZLOGI ZA PREKINITEV ŠPORTNE POTI ODRASLIH ARMENSKIH ORODNIH TELOVADCEV

Podatki o razlogih za prekinitev športne poti pri športnikih so bistvenega pomena, saj predstavljajo splošno osnovo za preprečevanje predčasne opustitve. Med 76 nekdanjimi orodnimi telovadci, ki so končali športno pot, smo izvedli sociološko raziskavo, da bi ugotovili vzroke za prekinitev športne poti. Ugotovljenih je bilo 11 različnih razlogov. Najpogostejši razlogi so športne poškodbe (35,52 %), obvezno služenje vojaškega roka (31,57 %) in zaposlitev (25,0 %). Najmanj omenjeni razlogi so težave z vaditeljem (5,26 %), zdravstvene težave (2,63 %) in starost (2,63 %). Raziskava ponuja širše razumevanje, zakaj armenski športniki prekinejo svojo športno pot. Ta vpogled bo vodstvenim organom armenske telovadbe in športa omogočil, da zagotovijo ciljno usmerjeno pomoč odraslim orodnim telovadcem, kar bo pomagalo preprečiti zgodnjo opustitev v prihodnosti.

Ključne besede: športna pot, zaključek, razlogi, orodna telovadba.

Thomas Lehmann, Klaus Knoll, Alexander Seemann-Sinn, Falk Naundorf

NAJVEČJE SILE ZA DOSEGANJE NAJBOLJŠE VIŠINI IN DALJAVE LETA NA PRESKOKU V MOŠKI ORODNI TELOVADBI?

Razčlenitev sil odriva na mizi za preskok lahko pomaga pri obveščanju športnika o tehniki izvedbe skokov. Merilna naprava je bila uporabljena za merjenje sil med Svetovnim prvenstvom v orodni telovadbi 2019. Največje sile so bile merjene med izvedbo premeta naprej. Povprečne najvišje vrednosti so bile 5,4-kratnik telesne teže (TT). Najvišja višina je bila izračunana pri premetu naprej (skrčeno) pri 2,9 m. Najdaljša razdalja leta je bila 3,62 m za premet naprej in 3,59 m za skok Tsukahara/Kasamatsu. Statistične povezave med silami ter najvišjo višino in razdaljo leta je bilo mogoče preveriti le za premet naprej. Za skoke Tsukahara/Kasamatsu in Yurchenko ni bilo mogoče dokazati nobene povezave.

Ključne besede: moška orodna telovadba, preskok, reakcijske sile.

Kolbjørn Lindberg, Hanne Sødal, Marie Salterød Sjåvik, Thomas Bjørnsen, Fredrik T Vårvik

IZBOLJŠANJE NASTOPOV V SKUPINSKIH AKROBATSKIH SESTAVAH Z VADBO MOČI

Prejšnje raziskave so poudarile močno povezavo med gibalnim delovanjem mišic spodnjih okončin in zmogljivostjo pri Skupinskih akrobatskih sestavah (SAS) zlasti v smislu ocen težavnosti pri skokih z male prožne ponjave in na akrobatski stezi. Do danes še nobena raziskava ni preverila, ali lahko izboljšanje delovanja mišic spodnjih okončin pomeni izboljšano učinkovitost pri SAS. V poskusno spremembo vadbe, ki je trajala šest tednov, smo vključili enajst telovadcev SAS na državni ravni (štirje moški, sedem žensk). Določene so bile vadbe moči trikrat na teden s poudarkom na moči in največji moči. Ocene pred in po spremembi vadbe so vključevale skoke z nasprotnim gibanjem, skoke v globino, moč potiskanja z nogami, 20-metrski tek v najvišji hitrosti, dosežni skok, kot tudi razčlenitve posnetkov zmogljivosti na ponjavi in akrobatski stezi. Predvsem meritev moči potiska z nogami je pokazal močno povezavo z zmogljivostjo na ponjavi ($r=0,95$, $p<0,001$), medtem ko so bili rezultati skokov v globino močno povezani z zmogljivostjo na akrobatski stezi ($r=0,72$, $p<0,05$). Po vadbi je samo poskusna skupina pokazala statistično verjeten porast moči pritiska na noge. Poleg tega je poskusna skupina pokazala povprečno povečanje težavnosti za $0,15 \pm 0,2$ točke, v nasprotju z zanemarljivo spremembo nadzorne skupine ($0,0 \pm 0,2$). Glede na omejeno velikost vzorca v tej predhodni pilotni raziskavi rezultati zahtevajo previdno razlago. Kljub temu se ujemajo s predhodnimi ugotovitvami, ki kažejo, da lahko povečanje športnikove mišične zmogljivosti spodnjih okončin s ciljno usmerjeno vadbo moči koristno vpliva na uspešnost telovadcev SAS na državni ravni..

Ključne besede: Skupinske akrobatske sestave, vadba, tekmovalni nastop, sprememba vadbe

Ömer Özer, Recep Soslu, Erhan Devrilmez, Osman Uyhan, Meltem Devrilmez, Ismail Dogan

UČINKI TELOVADBE NA GIBLJIVOST IN MOČ PRI OTROCIH

Namen te raziskave je bil preučiti vplive telovadbe na gibljivost in moč telovadcev. Prostovoljno je sodelovalo 48 dečkov, starih od 5 do 7 let. Udeleženci so bili naključno razporejeni v dve skupini (poskusna skupina: n=24; starost 6,21±1,10 let, višina 114,18±19,98 cm, teža 22,38±4,09 kg in ITM 15,85±1,59 kg/m²; nadzorna skupina n=24 ; starost 6,87 ± 0,74 let, višina 114,18 ± 19,98 cm, teža 22,38 ± 4,09 kg in ITM 15,90 ± 2,72 kg/m²). Meritev skoka v daljino (SLJ), vesa v zgibi (BAH), upogibanje trupa 30 s (SUC), predklon v sedu (SRF) in meritve gibljivosti v mirovanju (SF) so bili uporabljeni za poskusno in nadzorno skupino. Za poskusno skupino je potekala vadba 12 tednov, tri dni na teden v trajanju 90 minut. Dvosmerna ANOVA s ponavljajočimi se meritvami (2 × 2) je bila uporabljena za vrednotenje povezav in glavnih učinkov za čas (pred testom v primerjavi s po testu) in skupino (poskusno v primerjavi s nadzorno) na odvisne spremenljivke telesne zmogljivosti Rezultati so pokazali, da obstaja statistično značilna razlika v vrednostih SUC in SRF za poskusno skupino glede na meritve pred in po izvedeni vadbi ($p<0,01$, $d=0,95$, $p<0,01$, $d=0,75$). Pri drugih vrednostih ni bilo bistvenih razlik. Glede na rezultate razlik v skupini po testiranju so bili udeleženci poskusne skupine boljši od tistih v nadzorni skupini glede vrednosti ($p<0,02$, $d=0,780$; $p<0,04$, $d=0,614$; $p< 0,00$, $d=2,11$). Kot zaključek je program telovadbe bistveno izboljšal moč in gibljivost telovadcev, starih 5-7 let.

Ključne besede: telovadba, vadba, moč, gibljivost, testi zmogljivosti.

Bartłomiej Patryk Hes in Ewa Nowacka Chiari

VITALNA ZMOGLJIVOST PLJUČ AKROBATOV NA PROŽNI PONJAVI, STARIH 10-13 LET

Meritve vitalne zmogljivosti (VC) so pomembno orodje pri ocenjevanju delovanja dihalnega sistema. Nizka raven vitalne zmogljivosti lahko kaže na zdravstvene težave, kot so astma, kronična obstruktivna pljučna bolezen in druga stanja dihal. Prostornina VC je odvisna od številnih dejavnikov, zlasti od moči dihalnih mišic, strukture telesa in prsnega koša, sodelovanje pljuč in prsnega koša, prehodnosti dihalnih poti, spola, dejavnikov okolja in telesne dejavnosti. Namen te raziskave je ugotoviti stopnjo vitalne zmogljivosti (VK) pri deklicah in dečkih, starih od 10 do 13 let, ki se ukvarjajo s skoki na veliki prožni ponjavi, in rezultate primerjati z običajnimi vrednostmi za določen spol in starostno skupino. Raziskavo smo izvedli med 100 akrobati na prožnih ponjavah (od tega 57 deklet in 43 dečkov), starih od 10 do 13 let. V okviru raziskave je bila izvedena spirometrična meritev s prenosnim spirometrom EasyOne model 2001. Dobljene rezultate smo nato primerjali z običajnimi vrednostmi, izračunanimi na podlagi raziskave European Respiratory Society. Povprečna raven vitalne zmogljivosti pri deklicah, starih 10 let, je bila 2,2 litra, pri 11-letnicah - 2,45 l, pri 12-letnicah 2,54 l, pri 13-letnicah pa 3,02 l. Povprečna stopnja vitalne zmogljivosti preiskovanih dečkov, starih 10 let, je bila 2,36 l, pri 11-letnikih 2,56 l, pri 12-letnikih 2,89 l in pri 13-letnikih 3,33 l. Rezultati teh raziskav kažejo, da akrobati na veliki prožni ponjavi kažejo vrednost VC znotraj referenčnih vrednosti (med vrednostma LLN in ULN). Deklice izstopajo z višjim odstotkom napovedanih vrednosti za VC pri 11 (95,26 %) in 13 letih (100,34 %) v primerjavi z dečki pri 10 letih (96,38 %) in 12 (96,23 %).

Ključne besede: akrobatika na ponjavah, spirometrija, vitalna zmogljivost.

Sedat Kahya, Gökhan Deliceoğlu, Yeliz Ay Yıldız, Ercan Ayılgan in Sabahat Kahya

POVEZAVA NEKATERIH SPREMENLJIVK POLOŽAJA STEGNJENIH ROK PRI POVLEKU V STOJO NA ROKAH PRI ORODNIH TELOVADCIH

Cilj te raziskave je bil preveriti povezavo položajev med povlekom v stojo na rokah z odprtimi in zaprtimi očmi v desno-levi bočni ravnini pri orodnih telovadcih. Za ovrednotenje podatkov je bila izvedena razčlenitev povezav. Glede na ugotovitve pridobljene z razčlenitvijo v desni in levi ravnini pri 0°, je bila opažena statistično značilna povezava tako v negativni kot v pozitivni smeri. Razčlenitev povleka v stojo na rokah z odprtimi in zaprtimi očmi, merjeno v desni in levi ravnini pod kotom 90°, je pokazala statistično značilno povezavo tako v negativni kot pozitivni smeri. Podobno je razčlenitev povleka v stojo na rokah z odprtimi in zaprtimi očmi, merjeno v desni in levi ravnini pri 180°, pokazala statistično značilno korelacijo tako v negativni kot pozitivni smeri. V naši raziskavi smo ugotovili, da širši trikotnik, ki ga v začetnem položaju potiska v stojo na rokah z odprtimi očmi sestavljajo telovadčeva ramena, boki in stopala telovadcev, kaže na slabo začetno tehniko. Med izvajanjem povleka v stojo na rokah z odprtimi in zaprtimi očmi pri 90° zaznavanje položajev telesa deluje drugače v desni in levi ravnini. Med izvajanjem povleka v stojo na rokah z odprtimi in zaprtimi očmi pri 180° lahko centralni živčni sistem igra pomembno vlogo za mišice roke v desni ravnini pri ohranjanju želenega ravnotežja v odsotnosti vida.

Ključne besede: stoja na rokah, telovadba, ravnine, položaj, zanavanje.

Merve Koca Kosova in Sercin Kosova

ALI JE SPREMEMBA TOČKOVNEFGA PRAVILNIKA V SKOKIH NA VELIKI PROŽNI PONJAVI 2022-2024 SPREMENILA REZULTAT TELOVADCEV?

Tehnični odbor je po olimpijskih igrah v Tokiu 2020 posodobil pravila ocenjevanja skokov na veliki prožni ponjavi, kar je zlasti vplivalo na predtekmovanje. Prej so se v prvi sestavi za točke težavnosti upoštevale le štiri prvine, zdaj pa v obeh sestavah štejejo vse izvedene prvine. Za oceno vpliva so bili razčlenjeni podatki z 28. in 29. svetovnega prvenstva FIG v skokih na veliki prožni ponjavi v mlajših starostnih skupinah in 35. in 36. svetovnega prvenstva FIG članov v skokih na veliki prožni ponjavi v letih 2021/2022. Primerjava med letoma 2021 in 2022 v izvedbi (E), težavnosti (D), času leta (TOF) in vodoravnem odmiku (HD) je bila narejena s t-testom. V članski vrsti so se povprečne vrednosti povečale v D, HD in skupnih rezultatih v letu 2022, s pomembnimi razlikami v izvedbi in skoraj pomembnimi v rezultatih TOF. V vseh drugih kategorijah so se povprečne vrednosti D, E, TOF, HD in skupni rezultati leta 2022 zvišale, čeprav brez statistično pomembne razlike. Trend k višjim ocenam v skladu z novimi pravili kaže na njihov vpliv, vendar lahko vlogo igrajo tudi neraziskani dejavniki. Za celovito razumevnje so potrebne nadaljnje raziskave.

Ključne besede: velika prožna ponjava, telovadba,sestava, pravila ocenjevanja.

Rodriguez-Redondo, Yeray, Denche-Zamorano Angel, Mendoza-Muñoz, Maria, Adsuar Jose C., Leon, Kiko

RAZČLENITEV ZNANSTVENEGA USTVARJANJA V SKLOPU ULIČNE VADBE Z AKROBATSKIMI SESTAVINAMI

V zadnjih letih se je povečalo število vadbenih dejavnosti, kot so »parkour«, »breakdance« ali telovadba (prosti slog ali ulična vadba). Te dejavnosti imajo skupne značilnosti, kot sta neurejen ulični izvor in osredotočenost na akrobacije. Namen te raziskave je bil razčleniti stanje znanstvenih publikacij povezanih s temi akrobatskimi uličnimi športi. Izvedena je bila bibliometrična razčlenitev z uporabo običajnih bibliometričnih načinov za znanstveno dokumentacijo, najdeno v revijah, indeksiranih v WoS in Scopus. Obdelavo in upodobitev podatkov smo izvedli s programoma Bibliometrix in Excel. Prepoznanih je bilo skupno 199 člankov objavljenih med letoma 1984 in 2024, kar kaže na eksponentno rast. Med temi je bilo 139 člankov povezanih s »parkourjem«, 48 z »breakdanceom« in 12 z ulično vadbo. Pregled 158 revij je pokazal, da so vsebovale sorodne izdaje, čeprav njihova porazdelitev ni bila v skladu z Bradfordovim modelom, saj prikazujeta samo dve področji. Med 417 prepoznanimi pisci je bilo 22 ocenjenih kot plodovitih in 12 uglednih. Francija se je izkazala za državo z največ prispevki, sledijo ji ZDA. 553 avtorskih ključnih besed je bilo razvrščenih v tri skupine, od katerih je bila vsaka povezana z enim od športov. Kot pomembnih je bilo izbranih 26 najbolj navajanih člankov, ki dokazujejo povezavo med porastom objav in širjenjem teh dejavnosti, predvsem zaradi televizijske izpostavljenosti. "International Journal of Sport Policy and Politics" se je izkazal za najbolj plodno revijo. Najpomembnejši avtorji, prepoznani v vsaki dejavnosti, so bili Signey Grosprêtre (»parkour«); Max Daniel Kauther in Christian Wedemeyer (»breakdance«); in Javier Sanchez-Martinez (ulična vadba).

Ključne besede: akrobatika; šport; telesna dejavnost; »parkour«; »breakdance«; ulična vadba.

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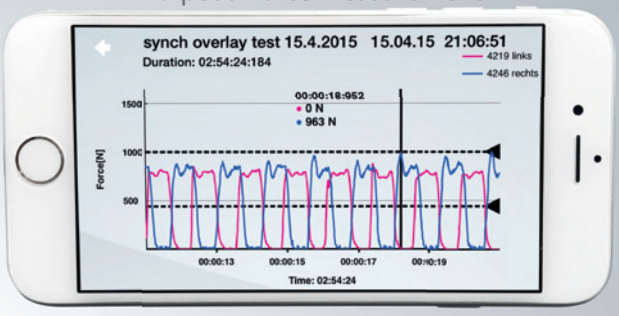

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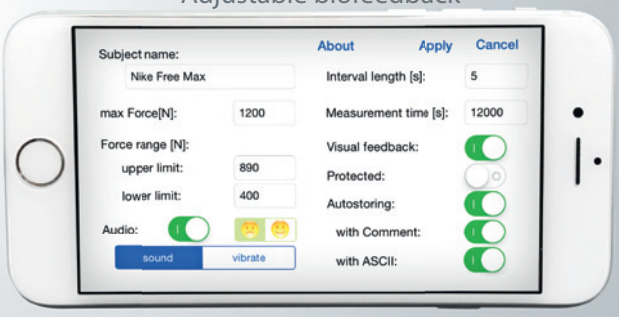

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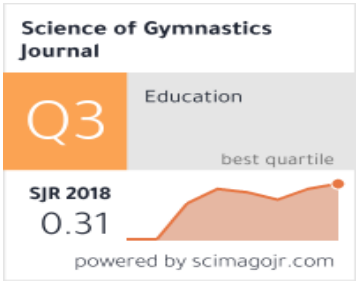

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