Review Paper

Systematic review of flexibility tests in gymnastics

MERCEDES VERNETTA, EVA MARÍA PELÁEZ-BARRIOS , JESÚS LÓPEZ-BEDOYA

Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain

ABSTRACT

The aim of this study was to review the tests used to measure flexibility in gymnastic disciplines. The search was conducted on PubMed, WOS, Scopus, Sport Discus and Google Scholar databases, and included studies in English and Spanish that assessed flexibility in gymnasts and were published between January 2005 and March 2020. Twenty-seven manuscripts were selected, rhythmic and women's artistic gymnastics being the most frequently studied disciplines. Flexibility was most commonly assessed in the hip and shoulder joints. Within the wide variety of tests performed, the most commonly used ones were the *split, shoulder flexibility, bridge* and *sit-and-reach* tests. Linear measurements were usually used, followed by the angular ones. In conclusion, in spite of flexibility being a determining capacity in gymnastic disciplines, several studies did not provide information on the validity of their results. Further studies including validated tests applied to larger samples and using longitudinal approaches are needed, with the aim to confirm test predictive validity and to allow for greater generalisation.

Keywords: Range of movement; Gymnastics; Flexibility tests.

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Corresponding author. *Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain.* https://orcid.org/0000-0002-8927-2082
E-mail: evapelaezbarrios@gmail.com
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INTRODUCTION

Gymnastic disciplines demand perfect execution of technical elements, where numerous components of fitness such as strength, speed, aerobic capacity, flexibility, power, balance, coordination and agility, as well as the anthropometric characteristics, are determining in sport success (Bobo-Arce & Méndez-Rial, 2013; Di Cagno, Battaglia, Fiorilli, Piazza, Giombini, Fagnani & Pigozzi, 2014; Douda, Toubekis, Avloniti & Tomakidis, 2008; Vernetta, Montosa, Beas Jiménez & López-Bedoya, 2017). Furthermore, in many of these disciplines, aesthetics and elegance need to be present as well (Miletić, Katić & Males, 2004; Vernetta, Fernández, López-Bedoya, Gómez-Landero & Oña, 2011).

From these capacities, most scientific evidence refers to flexibility as one of the greatest discriminators of gymnastics from other sports (Sands et al., 2016).

The fact that flexibility is a paramount component of fitness in these disciplines is not only because many of the technical elements that gymnasts must execute in their routines are basically flexibility movements, but also because it is essential in the execution of a large number of elements required in the different disciplines (Delas, Miletic & Miletic, 2008; León-Prados, Gómez-Piriz & González-Badillo, 2011; Vernetta, López & Gutierrez, 2008).

In this regard, Zetaruk (2000) and Sands, McNeal, Stone, Russell and Jemni (2006) referring to men's artistic gymnastics (MAG), Boligon, Paulo and Parra (2015) to rhythmic gymnastics, and Vernetta, Sánchez and López-Bedoya (2011) to aerobic gymnastics, stated that the degree of technical and artistic perfection that gymnasts achieve is determined to a great extent by the ROM they are able to reach during the execution of technical elements. In particular, high association was found between flexibility level and skill in rhythmic gymnasts (Boligon, et al., 2015), while active and passive hip-flexion flexibility were found to be associated with performance on pommel horse, parallel bars and horizontal bar in male gymnasts (León-Prados et al., 2011).

Flexibility may be defined as the range of motion (ROM) available to a joint or group of joints that does not result in pain (O´Connell, Posthumus & Collins, 2013). ROM is an angular measurement that determines the relative position of two body segments linked by a point in common: the joint. This angular variable is used to assess flexibility (López-Bedoya, Vernetta, Robles & Ariza, 2013).

Once some terms have been clarified and avoiding any terminological disquisition, this review aims to provide information on the flexibility tests and measurements used with gymnasts.

The main reason is that performance assessment in gymnasts is an essential step to determine not only their progress, but also their potential for this sport. Hence the importance of knowing which tests are the most appropriate to identify gymnasts with talent for this sport and also useful to trainers to detect asymmetries or differences in the flexibility level of body segments, in order to modify the training techniques to improve this capacity (Batista, Bobo & Ávila-Carvalho, 2015).

Due to the above reasons, the purpose of this study was to conduct a systematic review that provided updated information on the tests applied to assess flexibility in rhythmic-expressive gymnastic disciplines.

MATERIAL AND METHOD

The search was conducted on WOS, Scopus, PubMed, Sport Discus and Google Scholar databases, and comprised the following MeSH terms: "test" AND "flexibility" OR "range of movement" OR "stretching" AND "artistic gymnastics" "rhythmic gymnastics" "aerobic gymnastics" "acrobatic gymnastics" OR "trampoline". The inclusion criteria were: original manuscripts written in English or Spanish, studies conducted in men and/or women who practised one of these gymnastic disciplines: women's artistic gymnastics (WAG), men's artistic gymnastics (MAG), rhythmic gymnastics (RG), acrobatic gymnastics (ACG), aerobic gymnastics (AG) or trampoline gymnastics (TG), published in the last 15 years (between 1st January, 2005 and 30th March, 2020). The following exclusion criteria were applied: studies not including any of the aforementioned gymnastic disciplines, reviews or meta-analyses, studies conducted prior to 2005, studies with only an abstract published, communications or presentations, and studies written in a language other than English or Spanish.

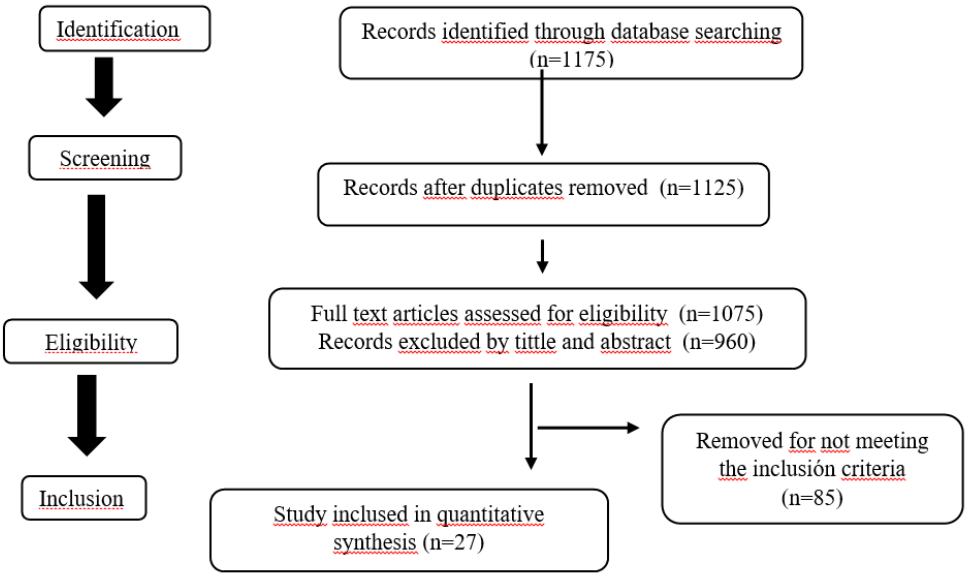

Figure 1. Search flowchart according to PRISMA Statement.

After the electronic search on all databases included in the study, 1,175 manuscripts were found; 50 of them were discarded for being duplicates, remaining 1,125. Additional searches were conducted using the first author's last name and the searching term "test" AND "flexibility" AND "gymnast" for the title. The references of selected manuscripts were screened to identify more potentially relevant papers. Subsequently, 50 papers were discarded for not belonging to the selected period and 1,075 were reviewed. After reading the abstract, 960 were removed for not meeting some of the criteria, obtaining 115. It is noteworthy that one of the only two manuscripts involving trampoline gymnastics was removed, since its aim was to determine the association between training time and gymnasts' sagittal morphotype (Sainz de Baranda, Santonja Medina & Rodríguez-Iniesta, 2010). While reading the abstracts, we were careful not to discard studies involving variables related to components of fitness in gymnasts, in case flexibility was included. In such case, and when the abstract did not provide sufficient information in that regard, the full text was read. Afterwards, 85 papers were discarded for not meeting the inclusion criteria. Twenty-seven papers were analysed following

PRISMA Statement guidelines to conduct a systematic review (Moher, Liberati, Tetzlaff, & Altman, 2009), which include the following four steps: identification, screening, eligibility and inclusion (Figure 1).

RESULTS

Firstly, Figure 2 shows the results divided by 5-year period and discipline.

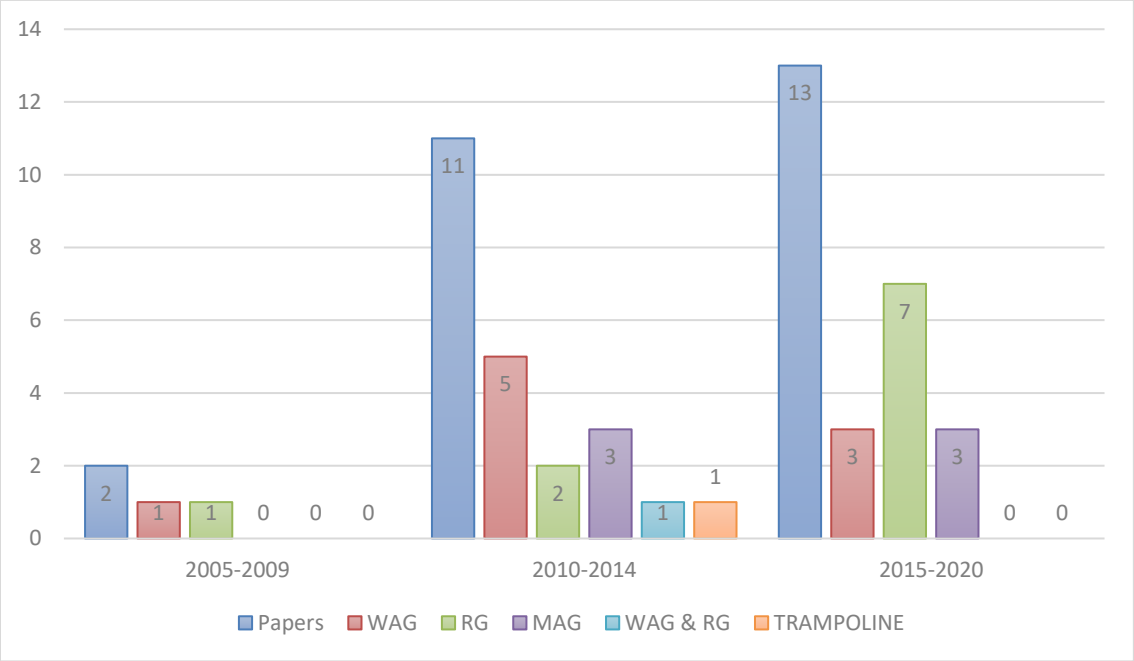

Figure 2. Manuscripts divided by 5-year period and gymnastic discipline.

The 5-year period containing the largest number of studies was the third one (2015-2020), with 13 papers (48.14%), followed by the second (2010-2014), with 12 papers (44.44%) and the first one (2005-2009), with only 2 papers (7.40%). As regards the gymnastic disciplines, the most frequently studied one was Rhythmic Gymnastics (10 papers), followed by Artistic Gymnastics (8 papers), Men's Artistic Gymnastics (6 papers) and Trampoline Gymnastics (only 1 paper). One study involved female gymnasts without specifying the discipline (Vandorpe et al., 2012) and another one compared rhythmic gymnasts with female artistic gymnasts (Leyton, Del Campo, Sabido & Morenas, 2012). No manuscript addressing Acrobatic Gymnastics or Aerobic Gymnastics was found.

The prevailing language was English, used in 19 papers (70.37%), while 7 (25.92%) papers were written in Spanish and 1 (3.70%) in Portuguese.

In general, the 27 studies selected were largely spread across different journals. Four papers were published in the Science of Gymnasts Journal, two in Biology of Sport, two in the International Journal of Sport Medicine and two in the International Journal of Sports Physical Therapy. The other 16 papers were all published in different journals.

The results from the 27 studies selected are shown in more detail in Table 1, specifying authors and year, sample and country (number of participants, age, gender, gymnastic discipline and country), capacities

assessed, tests, body segments under assessment, measurements taken and instruments used, if any. For those studies where more than one capacity was assessed, all of them were added to the table. However, only the tests and body segments related to flexibility were included, since that was the main aim of the present review.

Table 1. Studies including flexibility tests in gymnasts.

Authors and year	Sample and country	Capacities assessed	Flexibility tests	Body segments	Measurements
Arruda de Albuquerque & De Tarso Veras (2007)	55 female artistic gymnasts (age: 5-9 years) Brazil	Active and passive flexibility Power Dynamic strength Static strength Dynamic balance Coordination	5 tests: * Left/Right split test (2) *Shoulder flexibility test * Trunk flexion with separated legs (frog) * Trunk flexion with legs together	* Pelvis and lower extremities * Shoulder-complex flexion flexibility * Trunk: lower back and passive hip-abduction flexibility	Degrees
Douda et al. (2008)	34 rhythmic gymnasts (15 elite and 19 non-elite gymnasts) Mean age: 13.41 ± 1.62 years Greece	Active and passive flexibility Explosive strength Aerobic capacity Body dimensions Anaerobic metabolism Anthropometric measurements	8 tests: * Side splits with right and left legs (2) * Forward and sideward leg-lift tests with right and left legs (4) * Shoulder flexibility test * Sit-and-reach	*Pelvis and lower extremities * Shoulder-complex flexion flexibility * Trunk: lower back and flexibility	Longitudinal measurement (cm) Yardstick (cm)
Irurtia, Busquets, Carrasco, Ferrer & Marina (2010)	15 male artistic gymnasts (mean age: 11.4 ± 1.1 years) Spain	Active and passive flexibility	7 tests: * Side split and front split tests (2) * Side and front leg-raise tests (2) * Bridge test * Shoulder turn with stick (anteversion and retroversion) * Sit-and-reach	* Pelvis and lower extremities (PF) * Pelvis and lower extremities (AF) * Trunk/shoulder: Dorsal flexibility of back and shoulder * Shoulder-complex flexion flexibility * Trunk: lower back and lower limb: hamstring muscles	Trigonometric method Joint angles, measured in degrees through trigonometric formulae
Mazo (2010)	7 male gymnasts (mean age: 21.5 ± 5.5 years) Spain	Flexibility Jumping ability	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
León-Prados et al. (2011)	10 male artistic gymnasts 19-24 years Spain	Active and passive flexibility Strength Performance	3 tests: * Hip active and passive flexibility test in the sagittal plane (2) * Hip-abduction passive flexibility test from 90º flexion with straight legs	* Trunk-thigh: lower back and lower limb: hamstring muscles * Lower limb and hip flexion	Degrees Range of movement

Leyton et al. (2012)	25 gymnasts (13 female artistic gymnasts and 12 rhythmic gymnasts) Mean age:11.33 ± 1.15 years Spain	Flexibility Anthropometric measurements Strength Endurance Jumping ability	4 tests: * Front split * Shoulder flexibility with stick (anteversion and retroversion) * Low-back extension lying on the ground * Trunk flexion with straight legs and seating on a platform 40 cm above the ground	*Pelvis and lower extremities (PF) * Shoulder-complex flexion flexibility * Trunk: extensor muscles * Trunk: lower back and lower limb: hamstring muscles	Distance measured with measuring tape Longitudinal measurement (cm)
De Souza, Novaes & Fernandez-Filho (2012)	125 rhythmic gymnasts: 8 international-level, 10 national-level and 7 state-level gymnasts, 49 had reached menarche and 51 had not (7 to 25 years) Brazil	Basic physical capacities Flexibility Explosive strength Coordination	2 tests: * Spinal flexion * Leg extension (quadriceps)	* Trunk * Leg	Degrees Goniometer (360º)
Vandorpe et al. (2012)	23 female gymnasts (12 elite, 11 non-elite) 7-8 years	Flexibility Coordination	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
Sleeper, Kenyon & Casey (2012)	105 female artistic gymnasts (6 to 18 years of age) USA	*Flexibility *Speed *Power *Strength *Muscle endurance *Balance	4 tests: *Left/Right split and middle split tests (3) * The Shoulder Flexibility Test	*Pelvis and lower extremities * Shoulder-complex flexion flexibility	Longitudinal measurement (cm)/arm length
Gómez-Ladero, López-Bedoya, Vernetta (2013)	60 gymnasts (41 men and 19 women) divided into two groups by competition level (senior and U-15) and by gender. Mean age: from 11.44 ± 1.23 to 20.72 ± 4.66 Spain	* Active and passive flexibility	9 tests: * Active shoulder flexion * Passive shoulder flexion * Active shoulder extension * Passive shoulder extension * Active trunk flexion * Passive trunk flexion * Active trunk extension * Passive trunk extension *Passive hip abduction	* Shoulder flexion flexibility * Shoulder extension flexibility * Trunk: lower back and lower limb: hamstring muscles * Trunk: extensor muscles * Trunk: lower back and passive hip-abduction flexibility	ROM degrees
Dallas & Kirialanis (2013)	12 artistic gymnasts	Flexibility Jumping performance (explosive strength)	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)

	Mean age: 21.88 ± 1.05 years Greece Gender not specified				
Dallas, Kirialanis & Mellos (2014)	34 artistic gymnasts (15 boys and 19 girls) (mean age: 9.22 ± 1.34 years)	Flexibility Explosive strength	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
Dallas, Smirniotou, Tsiganos, Tsopani, Di Cagno & Tsolakis (2014)	18 artistic gymnasts (mean age: 21.83 ± 1.76 years) Gender not specified Country not specified	Flexibility Explosive strength	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
Tsopani et al. (2014)	11 rhythmic gymnasts Mean age: 17.54 ± 0.52 years Country not specified	Flexibility Explosive strength Endurance Balance	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm) Flex-Tester Box (Cranlea, UK)
Batista et al. (2015)	30 rhythmic gymnasts (mean age: 13.73 ± 0.17 years) Portugal	Active and passive lower-limb flexibility (dominant and non-dominant legs) Asymmetry	7 tests: * Split on two banks * Leg up with help of the hand: forward, sideways and backward (3) * Leg up without help of the hand: forward, sideways and backward (3)	* Pelvis and lower extremities (dominant and non-dominant)	Dimensionless method: comparison of joint ROM to an assessment scale (from 0 to 4 points) 0 = very low, 1 = low, 2 = average, 3 = good, 4 = excellent
Pion, Lenoir, Vandorpe & Segers (2015)	243 female artistic gymnasts Age: 6-9 years Flanders (Belgium)	Flexibility Leg explosive power Sprint Anaerobic endurance Coordination	1 test: * Sit-and-reach	* Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
Boligon et al. (2015)	20 rhythmic gymnasts (Age: 8-12 years) Panama	Active flexibility Validation of rhythmic gymnastics movements	2 tests: * Antero-posterior split * Trunk hyperextension lying prone with legs closed and arms outstretched	*Pelvis and lower extremities * Trunk: extensor muscles.	Degrees

Sleeper Kenyon, Elliot & Cheng (2016)	83 male gymnasts (7-18 years)	Active and passive flexibility Agility Balance Endurance	4 tests: * Left, right and middle split tests (3) * The Shoulder Flexibility Test	* Pelvis and lower extremities * Shoulder-complex flexion flexibility	Longitudinal measurement (cm)/arm length
Kritikou, Donti, Bogdanis, Donti & Theodorako (2017)	46 rhythmic gymnasts Mean age: 9.9 ± 1.3 years Greece	Flexibility Balance Muscle power Endurance Anthropometric measurements	2 tests: * Bridge test * Sit-and-reach	* Trunk and shoulder: dorsal flexibility of back and shoulder * Trunk: lower back and lower limb: hamstring muscles	Longitudinal measurement (cm)
Vernetta et al. (2017)	Rhythmic gymnasts 2 age groups Beginners level (6-11 years), advanced level (>12 years) Spain	Active and passive flexibility Balance Eye-hand coordination Agility Endurance Abdominal strength Hip flexor strength Propulsion strength	6 tests: * Split leaps with straight legs (2) * Forward leg lift and hold (right/left) (4) * Bridge * Shoulder flexibility	* Pelvis and lower extremities (passive flexibility) * Pelvis and lower extremities (active flexibility) * Trunk and shoulder: dorsal flexibility of back and shoulder	Degrees
Fraga et al. (2018)	13 rhythmic gymnasts (mean age: 14.5 ± 2.43 years) Brazil	Passive flexibility Strength	1 test: * Initial flexibility and hip flexion	* Pelvis and lower extremities (passive flexibility) * Pelvis and lower extremities (active flexibility)	Degrees (ROM)
Mkaouer, Hammoudi-Nassib, Amara & Chaabéne (2018)	51 male artistic gymnasts Mean age: 11.03 ± 0.95 Country not specified	Active and passive flexibility Speed Strength Coordination	7 tests: * Side/Right/Left split sit (3) * Forward leg lift (with the back on the wall) * Bridge (on hard mat) * Body bent (on the bench) * Active shoulder flexibility	* Pelvis and lower extremities (passive flexibility) * Pelvis and lower extremities (active flexibility) * Trunk and shoulder: dorsal flexibility of back and shoulder	Degrees Longitudinal measurement (cm)
Batista, Garganta & Ávila-Carvalho (2019b)	13 rhythmic gymnasts (9 from Brazil team, 9 from Portugal team) Mean age: 20.8 ± 1.9 years Brazil Portugal	Active and passive flexibility Explosive strength Endurance	7 tests: * Leg up with help of the hand: forward, sideways and backward (3) * Leg up without help of the hand: forward, sideways and backward (3) * Forward stand-and-reach test	* Pelvis and lower extremities (passive flexibility) * Pelvis and lower extremities (active flexibility) * Trunk: lower back, hip flexion	Dimensionless method: comparison of joint ROM to an assessment scale (from 0 to 4 points) 0 = very low, 1 = low, 2 = average, 3 = good, 4 = excellent Measurement (cm)
Lima, Brown, Li, Herat &	16 artistic gymnasts: Periodisation group (8) Mean	Flexibility Range of movement (ROM)	4 tests: * Hip flexor ROM * Hip extensor ROM * Dorsiflexion ROM	* Trunk: middle back and hip *Lower extremities: quadriceps	ROM degrees

Behm (2019)	age: 11.50 ± 0.95 years Non-periodisation group (8) Mean age: 12.12 ± 2.03 years Country not specified		* Hamstrings: sitting toe touch on the bench		
Batista, Garganta & Ávila-Carvalho (2019a)	157 rhythmic gymnasts (base level 82 gymnasts - mean age: 13.3 ± 2.0 years, 1st division 66 gymnasts - mean age: 13.5 ± 2.1 years, elite 9 gymnasts - mean age: 14.8 ± 1.8 years) Portugal	Active and passive flexibility	9 tests: * Leg up with help of the hand: forward, sideways and backward (3) * Leg up without help of the hand: forward, sideways and backward (3) * Shoulder rotation * Trunk lift lying prone on the floor * Forward stand-and-reach test	* Pelvis and lower extremities * Upper extremities * Trunk: lower back and lower limb: hamstring muscles	Degrees Hip ROM compared to a 5-point assessment scale
Ferri-Caruaca, Roig-Ballester & Romagnoli (2020)	18 female artistic gymnasts Mean age: 13 ± 2 years Spain	Flexibility Hip isometric strength Vertical jump performance	2 tests: * Hip extension lying prone with knee at 90º * Hip flexion lying supine with leg extended and neutral spine	* Hip flexion * Hip extension	Degrees
Gálvez, Téquiz, Chicaiza, Terán, Rodríguez & Carchipulla (2020)	12 male artistic gymnasts (7-13 years) Ecuador	Flexibility	3 tests: * Split * Bridge * Forward flexion	* Pelvis and lower extremities * Trunk/shoulder: dorsal flexibility of back and shoulder * Trunk: lower back and lower limb: hamstring muscles	Range and score → Five levels: 1=Poor 2=Satisfactory 3=Good 4=Very good 5=Excellent

DISCUSSION

The studies included in this review provided information on the different tests used to assess flexibility in gymnastic disciplines. This information will be discussed below based on the parameters analysed in the results.

Number of authors, sample size, gymnasts' age and country

The number of authors per manuscript ranged from one to eight. The majority were written by three (37.03%) or four (29.62%) authors. There was only one paper with one author and one with eight.

The total sample size of the studies varied within a wide range, from 7 in the study by Mazo (2010) to 243 in the study by Pion et al. (2015).

The reviewed manuscripts included gymnasts of various ages, from 5 to 25 years old, and very different age ranges. A high percentage of studies worked with samples of pre-adolescents and adolescents, while four studies (14.81%) involved young adults aged between 20 and 25 and only three studies (11.11%) involved children aged 5-9, 7-8 and 6-9, respectively. Five papers (18.51%) involved children and adolescents, four of them of ages ranging from 6-7 to 18 years old and one covering a much wider age range (7-25), since it focused on comparing rhythmic gymnasts based on their performance level.

The sample's country of origin was not specified in 22.22% of the studies. From the remaining 77.78%, the majority were conducted with Spanish gymnasts (22.22%). From these, the studies by Irurtia et al. (2010) in MAG and by Gómez-Landero et al. (2013) in TG must be highlighted as the only ones that addressed active and passive flexibility specifically, not including any other capacity or variable. Four studies involved gymnasts from Brazil (14.81%), three from Greece, three from Portugal (11.11% per country) and two from the USA (7.40%). There was one study involving gymnasts from each of the following countries: Panama, Belgium and Ecuador.

Capacities assessed

Six (22.22%) of the 27 papers only analysed flexibility, five (18.51%) analysed the pair flexibility-explosive strength and one (3.70%) worked with flexibility-coordination. Regarding the pair flexibility-strength, we must highlight the study by León-Prados et al. (2011), who related it with gymnastic performance on three MAG apparatus and found that passive hip-abduction flexibility with 90º flexion in the sagittal plane and upper-limb mean power (5-m climb) were associated with the best scores in pommel horse. There were three studies that assessed three capacities: one (3.70%) examined flexibility, explosive strength and coordination, one (3.70%) flexibility, explosive strength and endurance and one (3.70%) flexibility, explosive strength and isometric strength. The rest conducted a multidimensional assessment of four to six capacities including, apart from the above, speed, balance, static strength, dynamic strength, aerobic capacity or anthropometric measurements. Among these manuscripts, it is worth mentioning those that aimed to design and validate a full test battery to assess physical capacities based on the discipline and its motor profile. Some noteworthy studies are the one by Arruda de Albuquerque et al. (2007), conducted with Brazilian female artistic gymnasts, two more recent ones carried out in the USA in WAG and MAG, respectively (Sleeper et al., 2012; Sleeper et al., 2016), and the one by Vernetta et al. (2017) in rhythmic gymnastics. All these four studies involving test batteries included active and passive flexibility; in particular, passive mobility of the pelvis and lower extremities and active mobility of the shoulder girdle.

Tests performed, reliability and validity

In most of the selected studies and gymnastic disciplines, the most frequently used test was the *split*, which was applied in 9 studies (33.33%). It is a very widely used test in rhythmic-expressive gymnastic disciplines that allows for assessment of hip and leg mobility; it is a difficulty element to be executed in many of these disciplines and is also considered to be the flexibility reference standard in WAG and MAG (Smolevky & Gaverdovsky, 1996).

It must be underlined that all studies where only flexibility was assessed included active or passive mobility tests involving the shoulder and hip-lower limb joints, the *shoulder flexibility test* and the *split test* being the most popular ones (Sands, 2000; Smolevky & Gaverdovsky, 1996).

Likewise, these two tests were also included in other gymnastics-specific test batteries (Arruda de Albuquerque et al., 2007; Sleeper et al., 2012; Sleeper et al., 2016; Vernetta et al., 2017). In this regard,

Donti et al. (2016) pointed out that one characteristic that distinguishes top-level gymnasts from the rest is shoulder and hip flexibility.

The *forward, sideways and backward leg lift tests* were frequently used in studies with rhythmic gymnasts (Batista et al., 2015; Batista et al., 2019; Douda et al., 2008).

The *bridge test* is also one of the most commonly used tests (Gálvez et al., 2020; Irurtia et al., 2010; Kritikou et al., 2017; Mkaouer et al., 2018; Vernetta et al., 2017).

The *sit-and-reach test* was usually conducted in studies that aimed to examine the effects of some stretching technique on jumping performance (power) during gymnastics training (Dallas et al., 2014; Dallas & Kirialanis, 2013; Douda et al., 2008; Kritikou et al., 2017; Mazo, 2010; Pion et al., 2015; Tsopani et al., 2014).

This test allows for assessment of hamstring muscle and lower-back flexibility. It has been widely used in different populations, showing high intra-tester reliability measured through ICC, which yielded values of 0.89-0.99 (Sainz de Baranda et al., 2012). The simplicity and swiftness of the test application has helped it gain popularity.

This flexibility test was included as well in most of the manuscripts that addressed the assessment of several capacities considered essential for gymnasts (Arruda de Albuquerque et al., 2007; Douda et al., 2008; Kritikou et al. 2017; Pion et al. 2015; Tsopani et al. 2014). Its justification could be explained by the motor demands of many gymnastic elements of the different disciplines, where the pike shape (hip flexion with knees straight and legs together) is essential for correct execution (Fédération Internationale de Gymnastique, 2017). In particular, the study by Gómez-Landero et al. (2013) in trampoline gymnastics emphasised trunk flexion and shoulder flexion as the most demanding ones in terms of mobility for gymnasts of this discipline.

Validity and reliability of the tests applied was not assessed in a high percentage of studies. Among those that performed reliability tests we can mention studies in MAG (Irurtia et al., 2010; León-Prados et al., 2011; Mkaouer et al., 2018; Sleeper et al., 2016), WAG (Sleeper et al., 2012), RG (Kritikou, el t al 2017) and in MAG and WAG in the sit-and-reach test (Dallas et al., 2014).

The majority of manuscripts that addressed the design and validation of test batteries included content validation through expert judgement (Arruda de Albuquerque et al., 2007; Sleeper et al., 2012; Sleeper et al., 2016; Vernetta et al., 2017). In particular, construct validity, cross-validity and inter- and intra-observer reliability was tested for the battery proposed by Arruda de Albuquerque et al. (2007) for WAG. The results suggested adequate validity and reproducibility, allowing for application to initial talent detection in this discipline. Construct validity and test-retest reliability was assessed by Sleeper et al. (2012, 2016) for the two batteries proposed for WAG and MAG, respectively, obtaining satisfactory results.

Five studies applied tests proposed by the International Gymnastics Federation to measure flexibility, four of them in RG (Batista et al., 2015; Batista et al., 2019a, 2019b; Boligon et al., 2015) and one in MAG (Mkaouer et al., 2018). Despite the fact that validity and reliability of these tests have not been assessed, they are very useful to trainers and very interesting for establishing a unified means of specific functional capacity assessment, using the same criteria for all gymnasts and allowing for quantification of these capacities in different populations and reference groups.

According to the review study conducted by Sainz de Baranda, Ayala, Cejudo and Santonja (2012), the validity of the sit-and-reach test for hamstring flexibility assessment was moderate (0.37-0.85), especially in young adults and school students. They reported lack of validity assessment in samples of athletes and physically active participants.

In the rest of studies, a large number of tests were selected because they had been previously validated, but no reliability data were provided (Dallas et al., 2014; Dallas et al., 2012; Douda et al, 2008; Ferri-Caruaca et al.,2020; Fraga et al, 2018; Mazo, 2010; Pion et al., 2015; Tsopani et al, 2014; Vandorpe et al.,2012). It is important to be careful in this respect, since test validity is never universal or permanent. That is, validity will always depend on the participants' specific characteristics, as well as on the measuring conditions.

Instruments and measurements

The vast majority of measurements taken in the different tests of the 27 studies were linear (cm), followed by the angular (degrees) ones. It is noteworthy that Irurtia et al. (2010) applied the trigonometric method to calculate ROM in the different tests, preventing linear measurements from being compromised by the gymnast's anthropometric parameters.

Among the instruments used, we must underline the trigonometric method (Irurtia et al., 2010), measuring tape (Leyton et al., 2012), goniometer (360º) (De Souza et al., 2012), dimensionless method consisting in comparison of joint ROM to an assessment scale (Batista et al., 2015; Batista et al., 2019), code of points and posture analysis through video recording (Boligon et al., 2015), manual goniometer (Fraga et al., 2018), Kinovea, specific software for 2D movement analysis (Ferri-Caruaca et al., 2020), and cameras or camcorders in the rest of studies that used degrees or longitudinal measurements (cm).

CONCLUSIONS

In conclusion, according to our review, the most frequently studied disciplines were rhythmic gymnastics and women's artistic gymnastics, followed by men's artistic gymnastics. Only one manuscript involving trampoline gymnastics and none involving acrobatic or aerobic gymnastics were found in the databases. Active and passive flexibility were assessed in all studies that addressed this capacity specifically, the most commonly used tests being the split test, the shoulder flexibility test, the bridge test and the sit-and-reach test.

In spite of flexibility being a determining capacity in gymnastic disciplines, several studies did not provide information on the validity of their results. Furthermore, given the seemingly systematic selection processes, the data available are still insufficient to draw sound conclusions regarding flexibility assessment and the construction of reference scales.

Therefore, further studies including validated tests applied to larger samples and using longitudinal approaches are needed, with the aim to confirm test predictive validity and to allow for greater generalisation.

AUTHOR CONTRIBUTIONS

MV, contributed to the conception and design of the study and supervised the study. EP performed the bibliographic search in the different bases. EP, MV selected and evaluated the articles for inclusion and JL-B verified their inclusion. EP organized the database and performed the review analysis. MV and EP wrote the first draft of the manuscript. MV revised the writing of the article (grammar and spelling). JLB revise the

paper and managed his English translation. All authors contributed to manuscript revision, read and approved the submitted.

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No potential conflict of interest was reported by the authors.

REFERENCES

Arruda de Albuquerque, O. & De Tarso Veras Farinatti, P. (2007). Development and validation of a new system for talent selection in female artistic gymnastics: the PDGO Battery. Rev Bras Med Esporte, 13(3), 139–145.

Batista, A., Bobo, M. & Ávila-Carvalho, L. (2015). Flexibilidad en gimnasia rítmica: asimetría funcional en gimnastas júnior potuguesas. Apunts Educación Física y Deporte, 120(2), 19–26. https://doi.org/10.5672/apunts.2014-0983.es.(2015/2).120.03

Batista, A., Garganta, R. & Ávila-Carvalho, L. (2019a). Flexibility and Functional Asymmetry in Rhythmic Gymnastics. Athens Journal Os Sports, 6(2), 77–94. https://doi.org/10.30958/ajspo.6-2-2

Batista, A., Garganta, R. & Ávila-Carvalho, L. (2019b). Flexibility and strength in brazilian and portuguese gymnasts. European Journal of Human Movement, 42, 138–154.

Bobo-Arce, M. & Méndez-Rial, B. (2013). Determinants of competitive performance in rhythmic gymnastics. A review. Journal of Human Sport & Exercise, 8(3), 711–717. https://doi.org/10.4100/jhse.2013.8.proc3.18

Boligon, L., Paulo, P. & Parra, I. (2015). Influence of flexibility in the execution of movements in rhythmic gymnastics. Acta Scientiarium. Health Sciences, 37(2), 141–145. https://doi.org/10.4025/actascihealthsci.v37i2.21615

Dallas, G., Dallas, C. & Simatos, J. (2016). Nutritional status and dietary assessment of elite female artistic and rhythmic gymnasts-a case study. Sciencie of Gymnastics Journal, 8(3), 255–270.

Dallas, G., Kirialanis, P. & Mellos, V. (2014). The acute effect of whole bodt vibration training on flexibility and explosive strength of young gymnasts. Biology of Sport, 31(3), 233–237.

Dallas, G., Smirniotou, A., Tsiganos, G., Tsopani, D. Di Cagno, A. & Tsolakis, C. (2014). Acute effect of different stretching methods on fexibility nd jumping performance in competitve artistic gymnasts. J Sports Med Phys Fitness, 54, 683–690.

Dallas, G. & Kirialanis, P. (2013). The effect of two different conditions f whole-body vibration on flexibility and jumping performance on artistic gymnasts. Science of GYmnastics Journal, 5(2), 67–77.

De Souza, L., Novaes, J. & Fernandez-Filho, J. (2012). Qualidades físicas de atletas e practicantes de Ginástica Rítmica pré e pós-púberes. Revista Salud Pública, 14(2), 238–247. https://doi.org/10.1590/s0124-00642012000200005

Delas, S., Miletic, A. & Miletic, D. (2008). The influence of motor factors on performing fundamental movement skills – the differences between boys and girls. Physical Education and Sport, 6(1), 31–39.

Di cagno, A., Battaglia, C., Fiorilli, G., Piazza, M., Giombini, A., fagnani, F., & Pigozzi, F. (2014). Motor learning as Young Gymnast's talent Indicator. Journal of Sports Science and Medicine, 13, 767–773.

Donti, O., Bogdanis, G. C., Kritikou, M., Donti, A., & Theodorakou, K. (2016). The relative contribution of physical fitness to the technical execution score in youth rhythmic gymnastics. Journal of Human Kinetics, 50(2), 143–152. https://doi.org/10.1515/hukin-2015-0183

Douda, H., Toubekis, G., Avloniti, A. & Tomakidis, S. (2008). Physiological and Anthropometric Determinants of Rhythmic Gymnastic Performance. Int J Sports Physiol Perform., 3, 41–54. https://doi.org/10.1123/ijspp.3.1.41

Fédération Internationale de Gymnastique. (2017). Código de Puntuación de Gimnasia Artística Masculina (Lausane: F).

Ferri-Caruaca, A., Roig-Ballester, N. & Romagnoli, M. (2020). Effect of dynamic range of motion and static stretching techniques on flexibility, strength and jump performance in female gymnasts. Science of Gymnastics Journal, 12(1), 87–100.

Fraga, G., Ribeiro, A., Andrade, S., Antoni, L., Angelo, R., Da Silva, D. & Motta, M. D. (2018). The acute effect of a sport-specific stretching routine on the performance of vertical jumps in rhythmic gymnasts. Journal of Exercise Physiology, 21(2).

Gálvez, N.J., Téquiz, W.F., Chicaiza, C.A., Terán, R.J., Rodríguez, S.R. & Carchipulla, S. C. (2020). Potenciación de la capacidad flexibilidad en la gimnasia artistica masculina infantil. Lecturas de Educación Física y Deportes, 24(261), 46–56. https://doi.org/10.46642/efd.v24i261.1943

Gómez-Landero Rodríguez, L.A., López Bedoya, J., Vernetta Santana, M. (2013). Evaluación de la flexibilidad activa y pasiva en trampolinista españoles. Revista Internacional de Medicina y Ciencias de La Actividad Física y Del Deporte, 13(49), 55–72.

Irurtia, A., Busquets, A., Carrasco, M., Ferrer, B. & Marina, M. (2010). Control de la flexibilidad en jóvenes gimnastas de competición mediante el método trigonométrico: un año de seguimiento. Apunts Medicina de l'Esport, 45(168), 235–242. https://doi.org/10.1016/j.apunts.2010.05.003

Kritikou, M., Donti, O., Bogdanis, G.C., Donti, A. & Theodorakou, K. (2017). Correlates of artistry performance scores in preadolescents rhythmic gymnasts. Science of GYmnastics Journal, 9(2), 165–177.

León-Prados, J.A., Gómez-Piriz, P.T. & González-Badillo, J. J. (2011). Relación entre test físico específicos y rendimiento en gimnastas de elite. Revista Internacional de Ciencias Del Deporte, 22(7), 58–71. https://doi.org/10.5232/ricyde2011.02206

Leyton, M., Del Campo, V.L., Sabido, R. & Morenas, J. (2012). Perfil y diferencias antropométricas y físicas de gimnastas de tecnificación de las modalidad de artística y rítmica. Retos. Nuevas Tendencias En Educación Física, Deporte y Recreación, 21, 58–62.

Lima, C.D., Brown, L.E., Li, Y., Herat, N. & Behm, D. (2019). Periodized versus Non-Periodized stretch training on gymnasts flexibility and performance. International Journal of Sports Medicine, 40(12), 779–788. https://doi.org/10.1055/a-0942-7571

López-Bedoya, J., Vernetta, M., Robles, A. & Ariza, L. (2013). Effect of three types of flexibility training on active and passive hip range of motion. Sports Med Phys Fitness, 53(3), 304–311.

Mazo, L. (2010). Efectos del entrenamiento con plataforma vibratoria en gimnastas de alto rendimiento. Revista Kronos, 9(18), 69–75.

Miletić, D., Katić, R., & Males, B. (2004). Some anthropologic factors of performance in rhythmic gymnastics novices. Collegium Antropologicum, 28(2), 727–737.

Mkaouer, B., Hammoudi-Nassib, S., Amara, S. & Chaabéne, H. (2018). Evaluating the physical and basic gymnastics skills assessment for talent identification in men's artistic gymnastics proposed by the International Gymnastics Federation. Biology of Sport, 35(4), 383–392. https://doi.org/10.5114/biolsport.2018.78059

Moher, D., Liberati, A., Tetzlaff, J. & Altman, D. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ, 339, 332–336. https://doi.org/10.1136/bmj.b2535

O´Connell, K., Posthumus, M. & Collins, M. (2013). No association between COL3A1, COL6A1 or COL12A1 gene variants and range of motion. J Sports Sci., 31, 181–187.

Pion, J., Lenoir, M., Vandorpe, B. & Segers, V. (2015). Talent in female Gymnastics: A survival analysis based upon performance characteristics. International Journal of Sports Medicine, 36, 935–940. https://doi.org/10.1055/s-0035-1548887

Sainz de Baranda, P., Ayala, F., Cejudo, A. & Santonja, A. (2012). Descripción y análisis de la utilidad de las pruebas sit-and-reach para la estimación de la flexibilidad de la musculatura isquiosural. Revista Española de Educación Física y Deportes, 396, 119–133.

Sainz de Baranda, P., Santonja Medina, F. & Rodríguez-Iniesta, M. (2010). Tiempo de entrenamiento y plano sagital del raquis en gimnastas de trampolín. Revista Internacional de Medicina y Ciencias de La Actividad Física y Del Deporte, 10(40), 521–536.

Sands, W.A., McNeal, J.R., Stone, M.H., Russell, E.M. & Jemni, M. (2006). Flexibility enhancement with vibration: acute and long-term. Med Sci Sports Exerc, 38, 720–725. https://doi.org/10.1249/01.mss.0000210204.10200.dc

Sands, W.A., McNeal, J.R. Penitente, G., Ross, S., Nassar, L. Jemni, M…Stone, M. H. (2016). Stretching the spines of gymnasts: A review. Sports Med., 46, 315–327. https://doi.org/10.1007/s40279-015-0424-6

Sands, W. A. (2000). Olympic. Preparation Camps 2000-Physical Abilities Testing. Technique, 20, 6–19.

Sleeper, M.D., Kenyon, L.K., & Casey, E. (2012). Measuring in Female Gymnasts: The Gymnastics Functional Measurement Tool. Internacional Journal of Sports Physical Therapy, 7(2), 124–138.

Sleeper, M.D., Kenyon, L.K., Elliot, J.M. & Cheng, M. S. (2016). Measuring Sport-Specific Physical Abilities In Male Gymnasts: The Men's Gymnastics Functional Measurement Tool. The Internacional Journal of Sports Physical Therapy, 11(7), 1082–1100.

Sleeper, M. D. (2016). Medición de las habilidades físicas específicas del deporte en gimnastas masculino: La gimnasia masculina herramienta de medición funcional. The Internacional Journal of Sports Physical Therapy, 11(7), 1082.

Smolevky, V., & Gaverdovsky, I. (1996). Tratado general de gimnasia artística deportiva (Paidotribo).

Tsopani, D., Dallas, G. Tsiganos, G., Papouliakos, S., Di Cagno, A., Korres, G., Riga, M & Korres, S. (2014). Short-term effect of whole-body vibration training on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts. Human Movement Science, 33, 149–158. https://doi.org/10.1016/j.humov.2013.07.023

Vandorpe, B., Vandendriessche, J.B., Vaeyens, R., Pion, J., Lefevre, J., Philippaerts, R.M. & Lenoir, M. (2012). The value of a non-sport-specific motor test battery in predicting performance in young female gymnasts. Journal of Sport Science, 30(5), 497–505. https://doi.org/10.1080/02640414.2012.654399

Vernetta, M., Fernández, E., López-Bedoya, J., Gómez-Landero, A., Oña, A. (2011). Estudio relacional entre el pérfil morfológico y estima corporal en la selección andaluza de gimnasia rítmica. Motricidad. European Journal of Human Movement, 26, 77–92.

Vernetta, M., López, J. & Gutierrez, A. (2008). La creatividad en la Gimnasia Acrobática. Creatividad y Deporte: Consideraciones Teóricas e Investigaciones Breves.

Vernetta, M., Montosa, I., Ariza, L. & López Bedoya, J. (2019). Comparative analysis of adherence to the mediterranean diet among girls and adolescents who perform rhythmic gymnastics. Rev Bras Med Esporte, 25(4), 280–284. https://doi.org/10.1590/1517-869220192504175283

Vernetta, M., Montosa, I., Beas Jiménez, J. & López-Bedoya, J. (2017). Batería Funcional ARISTO en Gimnasia Rítmica: protocolo de test específicos para la evaluación de jóvenes gimnastas en un ámbito de entrenamiento saludable. Revista Andaluza de Medicina Del Deporte, 10(3), 112–119. https://doi.org/10.1016/j.ramd.2017.02.001

Vernetta, M., Sánchez, A. G., & López-Bedoya, J. (2011). Flexibilidad y gimnasia aeróbica de competición: esquemas de acción y orientaciones metodológicas. Lecturas: Educación Física y Deportes, 160, 6–12.

Zetaruk, M. N. (2000). The young gymnasts. Clin. Sports Med., 19, 757–780.