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Original Article

Joint mobility in physical education majors: A hierarchical clustering analysis

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Abstract
Introduction: Joint mobility has been considered an important component of the physical fitness. **Objective:** This STROBE-based study aimed to evaluate the joint mobility in undergraduate students of Physical Education. **Materials and methods:** Data measurements were obtained for 239 students attending from 4th to 9th academic semester of a physical education major (200 men: 22±4.3 years, 1.72±0.05 m, 67±8.5 kg; and 39 women: 21±3.4 years, 1.61±0.07 m, 57±6.4 kg). Flexibility expressed as a General/global Index of Joint Mobility (GIJM) was measured through the Flexitest method, which assesses the maximum passive range of motion (ROM) of 20 body joint movements. We also reported the profile of ROM for the individual movements of the Flexitest battery. **Results:** The differences found between sexes, highlight index of general articular mobility (GIJM) and ROM ($p < .05$). This aspect is also observed when comparing standardized joint limitations ($p < .01$ ankle, knee, hip, trunk, elbow and shoulders). However, the homogeneity profile range of movement in the intermovement variability index, the interjoint variability index and the flexion-extension variability index indices don´t reflect gender differences ($p > .05$), contrary to found in the between segment variability index and distal-proximal variability index ($p < .01$). **Conclusions:** The hierarchical clustering algorithm subdivided the study participants into groups according to GIJM. We identified two significantly different phenotypes representing younger, lighter, and with higher joint mobility (Cluster 1) versus older, heavier, and with lower joint mobility students (Cluster 2). More research is needed to evaluate associations with body composition, physical performance, quality of life and academic success.
Keywords: flexibility; physical examination; range of motion; unsupervised machine learning

Introduction

Etymologically, flexibility comes from the Latin *flexum* (bent), *bli* (that can) and *lity* (quality) The simplest definition considers flexibility as the range of motion (ROM) of a given joint (Araújo, 2004). Although several different definitions can be found in the literature, most of the authors incorporate the idea of maximum ROM without causing injury (Nuzzo, 2019). It is worth mentioning that flexibility should also encompass the passive movement to minimize bias in measuring ROM (Araújo, 2004). However, from a biomechanical point of view, muscles, bones and joints do not bend during the movement production. Therefore, any musculoskeletal movement would be limited by the structure of the bones, ligaments, muscle length, tendons, joint capsule and even the elasticity of the skin and adipose tissue. These are considered as uncontrolled internal factors that restrict the movement of one or more joints. Since ROM is a function of the condition of the joints, muscles, and connective tissues involved, we will intentionally use the term joint mobility instead of flexibility, considering it as "the possibility of movement of the joints, regardless of the amplitude of that movement" (Merino et al., 2011). Likewise, the ROM as the measurable and observable quantitative aspect of the joint to move over the arc of movement (Heredia & Chulvi-Medrano, 2011).

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The physical condition or physical fitness of a subject can be defined as the ability to perform effectively and vigorously activities of daily living (ADL) without excess of energy expenditure or fatigue while the injury incidence is kept low (Shephard, 1995). A low physical fitness has been considered as a predictor of cardiovascular risk (Artero et al., 2012; García-Hermoso, Cavero-Redondo, et al., 2018), obesity, dyslipidemia, hypercholesterolemia, hypertension, smoking, and diabetes mellitus (García-Hermoso, Ramirez-Velez, et al., 2018; Lavie et al., 2019). The physical fitness has several components that can be evaluated by exercise and/or health professionals, including cardiorespiratory fitness, muscle strength, speed-agility, motor coordination, body balance and joint mobility. Various studies have indicated the first two components as being of high importance when associating with health status, quality of life and the prevalence of non-communicable diseases (García-Hermoso, Cavero-Redondo, et al., 2018). This has led to certain "forgotten" components (such as joint mobility) during the development of exercise programs to improve physical fitness. Although stretching has been popularized as the way to train flexibility, other activities that cause more positive impact on health and quality of life (e.g., resistance training) are able to improve or maintain joint mobility and ROM (Afonso et al., 2021; Nuzzo, 2019). In this regard, various laboratory and in field instruments and techniques has been developed to assess joint mobility and ROM (Soucie et al., 2011). Due to their methodological and instrumental differences, we can group them into three categories based on Koryahin et al. 2021; Monteiro & Da Costa (2005): a) Angular tests, usually expressed in degrees of an angle formed by two body segments linked to a joint (e.g., goniometer); b) linear tests, usually expressed in centimeters (e.g., the sit-and-reach test); and, c) dimensionless tests, where no units are given for the interpretation of joint mobility. An alternative of this latter is the frequently used and validated Flexitest method. This was developed by Araújo (2004, 2008a) to evaluate twenty joint movements using an interpretation scale from 0 to 4.

Since the academic curriculum has shown to promote sedentary behavior in university students (Chaves- Franco et al., 2019), characterizing the physical condition of these majors has become an institutional objective to improve health and learning experiences (Sánchez et al., 2020). In fact, previous studies have found associations of computing-related postures (Menéndez et al., 2007), sitting posture (Casas et al., 2016), and sedentary patterns and non-ergonomic postures (Ogunlana et al., 2021) with back pain and/or upper-body musculoskeletal symptoms in college students. Additionally, undergraduate students belonging to a physical education major must develop different physical aptitudes as part of their formation (i.e., running, jumping, pushing, throwing, displacements in different directions and intensities). This also includes joint mobility which should be taken into account as part of the physical or sports activities and as an indicator of general health and quality of life. In this sense, several researchers has proposed the improvement in joint mobility as a mechanism to reduce the injury incidence, deficits in the ROM and muscle retractions affecting motor patterns needed for ADL (Giménez-Salillas et al., 2014; Grabara et al., 2010).

Joint mobility is an important component of the physical fitness. However, limited information is known about differences in flexibility among undergraduate students attending to a physical education major. Numerous investigations have focused their interest on evaluating physical qualities in school children, due to importance of sexual maturation, growth and physical-cognitive development, especially when observing the evolution during the course of different stages of development. In the same way, a great interest is established in athletes performance, as well as the establishment of reference values (Aedo-Muñoz, et al., 2019; Mocanu & Dobrescu, 2021), differentiating the study from physical quality mentioned in adults and especially in university population. Thus, the aim of this study was to characterize, for the first time, the joint mobility in these majors using a frequentist approach and unsupervised machine learning. One would expect them to have high passive ROM of joint movements.

Materials and methods

Study design

A cross-sectional observational study was performed. It was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology – STROBE guidelines (Vandenbroucke et al., 2009).

Setting

The study was carried out between from February to November 2019. This research was part of an accepted investigation project valid from 2019 to 2020 with the collaboration of the following Universities: the Corporación Universitaria Minuto de Dios and Fundación Universitaria del Área Andina. The study was designed in accordance with the ethical guidelines of the Declaration of Helsinki and the Resolution 8439 of 1993 of the Ministry of Health of Colombia. The research protocol was approved by the Research Committee of CUMD (code: 190215).

Participants

Undergraduate students over 18 years who were studying a 'Physical Education, Sports and Recreation' major of a private institution in Bogota, Colombia, were invited to participate. A total of 253 students accepted the invitation and were suitable for eligibility. The participants were academically enrolled and institutionally active at the moment of the assessment. The subjects voluntarily participated and were informed about the protocol and the aim of this research. All of them were physically active as they performed more than two (range: 2–5) exercise sessions per week (both endurance and strength training), but none of them performed exercise on an elite level.

Variables

The following continuous variables were measured: body mass (kg), stature (cm), and flexibility and several joint mobility indexes. Other variables were also collected from the informed consent (age and academic semester).

Data sources / measurement

The familiarization and data collection were performed in two sessions. In the first session, recommendations were given for the correct execution of the battery test including not having food 30 minutes previous to the assessments nor physical activity during the previous eight hours. In addition, participants were explained that one of the examiners would supervise the movements to avoid compromising technical execution while a second examiner would proceed with photography collection (for comparison with the standardized images of the test). During the second session, the data collection was made between 07:00 to 10:00 and 18:00 to 21:00 (GMT-5), time in which the participants were available. Bogotá city is located at 2630 meters above sea level with temperatures ranging from 9° to 14°C. Prior to testing, participants performed a general warm-up consisting of 10-min low-intensity jogging. After the warm-up, the twenty movements described in the Flexitest battery were performed.

Flexibility and joint mobility index

Flexibility expressed as a joint mobility index was measured through the Flexitest method developed by Araújo and colleagues (2004, 2008a). This test assesses the maximum passive ROM of twenty body joint movements (Table S1). The test was performed in the right side of the body avoiding on purpose bilateral comparisons. After the assessment of the twenty movements, the photography registration was contrasted to the standardized images provided by Araújo (2004) using an Excel template. Each movement was given a value that ranged from 0 to 4 (where 0 = very poor, 1 = poor, 2 = average, 3 = good, and 4 = Very good). Each assessment was revised by two examiners independently and in case of discrepancies the final assessment was determined by consensus.

After the assessment, the sum of all of obtained values was performed to calculate the General/global Index of Joint Mobility (GIJM, also called *Flexindex*). The classification of the GIJM was as follows: lower than 20 = very low, 21 to 30 = low, 31 to 40 = medium-low, 41-50 = medium-high, 51 to 60 = high, and more than 60 = very high. Furthermore, other indices were obtained including: i) the intermovement variability index (IMVI), that represents the variability of punctuations of all the assessed movements; ii) the interjoint variability index (IJVI), which expresses the variability of the ROM in the seven assessed joints; iii) the flexion-extension variability index (FEVI), which compares the ROM of the extension movements with the flexion ones; iv) the between segment variability index (BSVI), that compares the mobility of the lower limbs against the upper limbs; and v) the distal-proximal variability index (DPVI), which analyses the differences between the ROM of the distal joints (ankle, knee, wrist and elbow) regarding the proximal joints (hip and shoulder).

Data sources / measurement

Non-probability convenience sampling was used. After the announcement to participate in this study, only the college students that fulfill all inclusion criteria were considered as enrolled.

Statistical Analysis

The percentage of the GIJM difference between men and women was calculated as follows: Σ of the values obtained in the joint movements multiplied by 20, and divided by the number of movements evaluated of the joint. The values of IMVI, IJVI, FEVI, BSVI, and DPVI were utilized to calculate the homogeneity profile (also known as joint mobility profile) of the ROM according to Araújo (2004, 2008a). The Kolmogorov-Smirnov test was used to evaluate normality, while the Levene's to assess homoscedasticity. In addition, the participants were subdivided into clusters using unsupervised machine learning to identify similar data points (natural groupings) and extract profile patterns. The number of clusters was determined using 30 criterion algorithms comparing the two-to ten-cluster solutions with the R package '*NbClust*'. The internal validation for selecting the clustering method among k-means, k-medoids, hierarchical and CLARA was performed with the '*clValid*' package (Brock et al., 2008). Hierarchical clustering for k=2 showed better performance and, thereby, a dendrogram was plotted using bottom-up approach, where the length of an edge between a cluster and its split is proportional to the dissimilarity between the split clusters. This provides an easy-to-interpret view of the clustering structure (Wittek, 2014). The package 'Factoextra' was used to visualize the clustering results within the free software environment for statistical computing and graphics R v4.0.2 (R Development Core Team 2017). To analyze the differences between sex and clusters the U de Mann-Whitney test was used. The student's *t*-test for independent samples was used to compare the adjusted and standardized joint values among groups, and the homogeneity profile of the ROM. A level of significance of $p < .05$ was considered. The statistical analyses were performed using the Statistical Package for Social Science® software, version 22 (IBM Corp., Armonk, NY, USA).

Results

Three women were excluded due to pregnancy from the 253 potentially eligible participants. Eleven men were also excluded because of musculoskeletal injury or health condition that prevented them from completing the Flexitest (*n*=6), and due to high-performance athletic level (national and international competitors) (*n*=5). All data measurements were obtained for 239 subjects (200 men and 39 women). Students were attending from 4^{th} to 9^{th} semester of the physical education major. Age (years): men 22±4.3 vs. women 21±3.4; height (cm): men 172±5.0 vs. women 161±7.0; Body mass (kg): men 67±8.5 vs. women 57±6.4; Body Mass Index ($kg \cdot m^{-2}$): men 23±2.7 vs. women 22±2.6. The GIJM results showed a higher relative frequency of high and medium-high classification in women and men. Notwithstanding, a higher percentage of men were classified with very high joint mobility in comparison to women (Figure 1). The global score of the GIJM revealed that women (51.8±6.6) had significantly higher values than men (46.4±5.4) (p< .0001).

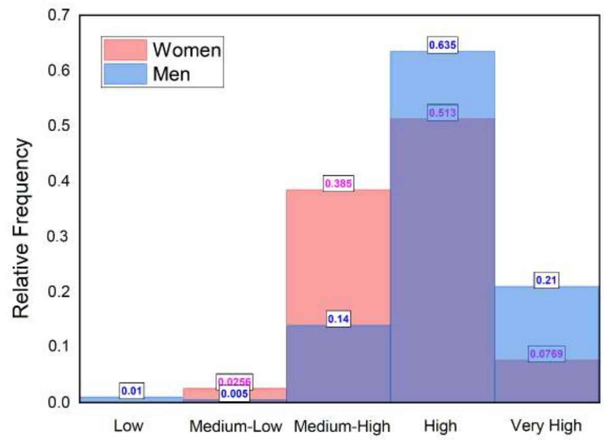

Figure 1. Relative frequency of the GIJM results.

By contrasting the different assessed joints in the Flexitest, we found that the adjusted and standardized joint values revealed between-sex differences. All the values for joints were significantly different excepting for wrist joint. Data distribution and the significant between-sex differences for all analyzed joints are shown in Figure 2. The U-Mann Whitney test showed that women presented a significantly higher ROM than men (p< .05) in most of the assessed movements (Table 1).

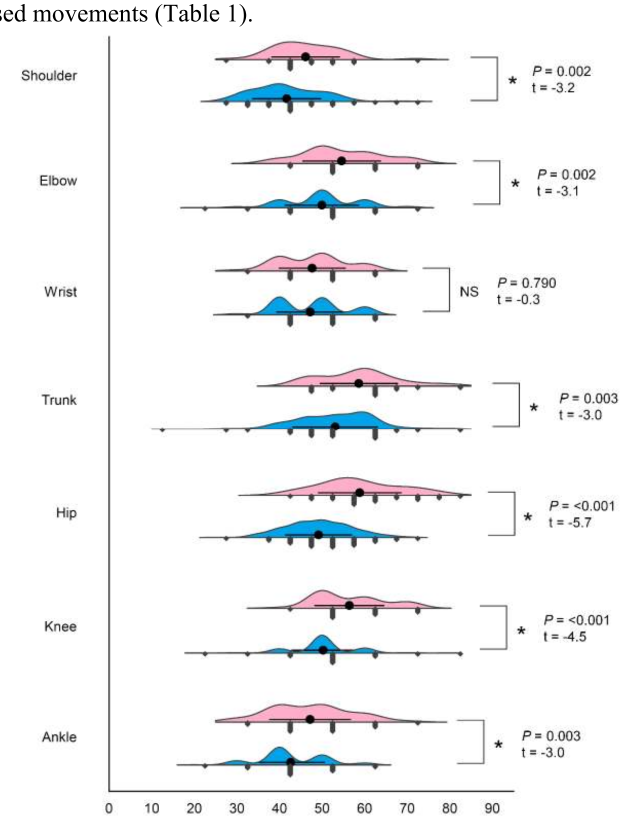

Figure 2. Horizontal half violin plots of the Flexitest values by joint.

This figure shows the distribution of the adjusted and standardized joint values in women (pink) and men (blue). Black circles represent the mean while dark grey diamonds the raw data.

Table 1.
Flexitest movements distinguished by sex.

Movement	Men (mean)	Women (mean)	% Difference	*Z*	*P*-Value
I	2.16	2.32	15%	-1.409	.159
II	2.10	2.39	29%	-2.940	.003**
III	2.93	3.21	28%	-3.347	.001**
IV	2.09	2.45	35%	-3.758	.000**
V	2.18	2.68	51%	-5.696	.000**
VI	2.18	2.74	55%	-3.542	.000**
VII	2.58	3.05	48%	-3.837	.000**
VIII	2.91	3.29	38%	-3.934	.000**
IX	2.62	2.84	23%	-1.992	.046*
X	2.71	3.08	37%	-3.357	.001**
XI	2.64	2.84	20%	-1.435	.151
XII	2.44	2.55	11%	-1.174	.240
XIII	2.28	2.21	-7%	-.755	.450
XIV	2.66	2.89	23%	-2.113	.035*
XV	2.33	2.58	25%	-2.171	.030*
XVI	2.36	2.53	16%	-1.305	.192
XVII	2.13	2.32	18%	-1.108	.268
XVIII	1.75	1.97	22%	-2.476	.013*
XIX	1.84	2.21	37%	-2.554	.011*
XX	2.34	2.53	19%	-1.263	.206

* Significant differences $p < .05$; ** Significant differences $p < .01$

Regarding the analysis of the homogeneity profile of the ROM, no statistically significant differences were found between men and women in the IMVI (*t* -.860; *p*= .391; *CI* 95%= -0.057, 0.022), in the IJVI (*t* -1.374; *p*= .171; *CI* 95%= -0.069, 0.012) nor in the FEVI (*t* 1.073; *p*= .284; *CI* 95%= -0.022, 0.075). Nevertheless, significant differences were found in the BSVI (*t* -2.939; *p*= .004; *CI* 95%= -0.125, -0.024) and in the DPVI (*t* 3.538; *p*= .001; *CI* 95%= 0.029, 0.105). The different indices of variability can be observed with more detail in Table 2.

Table 2. Analysis of the flexibility profile between sex.

	IMVI		IJVI		FEVI		BSVI		DPVI	
	M	W	M	W	M	W	M	W	M	W
Category	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)	f_i(%)
Very High	8(4)	1(2.6)	4(2.0)	2(5.1)	-	-	-	-	-	-
High	12(6)	2(5.1)	21(10.5)	4(10.3)	29(14.5)	2(5.1)	29(14.5)	13(33.3)	11(5.5)	3(7.7)
Normal	130(65)	30(76.9)	143(71.5)	27(69.2)	156(78)	25(64.1)	160(80)	26(66.7)	175(87.5)	35(89.7)
Low	47(23.5)	5(12.8)	23(11.5)	4(10.3)	13(6.5)	11(28.2)	11(5.5)	-	14(7)	1(2.6)
Very Low	3(1.5)	1(2.6)	9(4.5)	2(5.1)	2(1)	1(2.6)	-	-	-	-

IMVI: Inter Movement Variability Index; IJVI: Inter Joint Variability Index; FEVI: Flexion Extension Variability Index; BSVI: Between Segment Variability Index; DPVI: Distal Proximal Variability Index; M: Men; W: Women; f_i: Absolute frecuency; (%) Percentage. Note: The F base values reported by Araújo (2004; 2008) were used for the different indices of variability.

The *clValid()* function revealed that the hierarchical clustering analysis resulted more appropriated to cluster our data in comparison to other methods. Two clusters were identified: n = 182 (cluster 1) and n = 57 (cluster 2), as can be seen in Figure 3. Almost all women participants were classified in Cluster 1 (37/39) but this cluster also contain a large number of men (145/200). No relevant matching was found for the academic semester. Regarding the GIJM categories, Cluster 1 encompassed those participants classified in higher categories while Cluster 2 comprised a higher percentage of individuals in medium-low and small categories (Cluster 1: very high [2.74%], high [30.21%], medium-high [58.79%], medium-low [8.24%], low [0.0%]; and Cluster 2: very high [0.0%], high [12.28%], medium-high [61.40%], medium-low [24.56%], small [1.75%]).

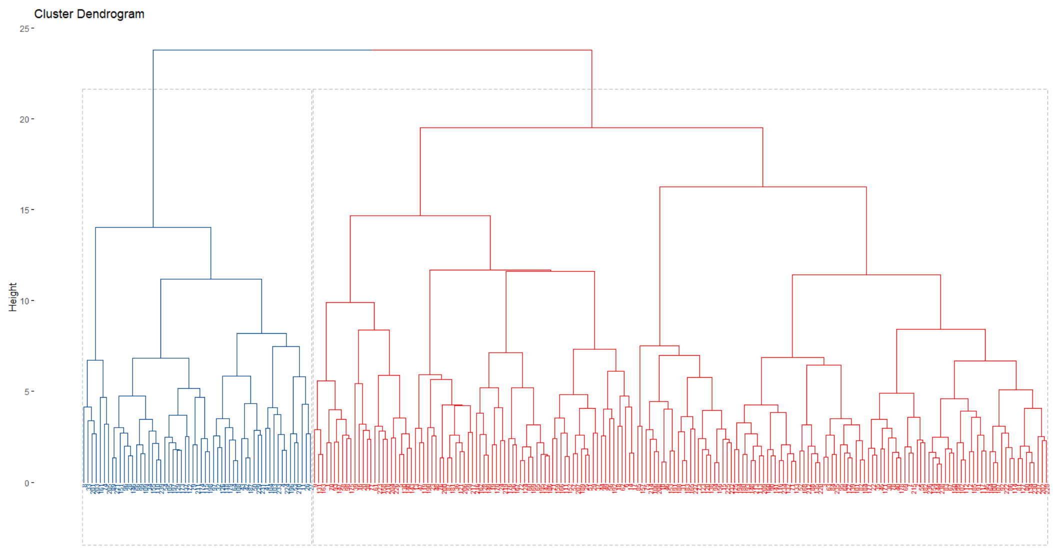

Figure 3. Dendogram of the bottom-up agglomerative clustering.
Each leaf corresponds to one student. Students that are similar to each other are combined into branches, which are themselves fused at a higher height. The height of the fusion, provided on the vertical axis, indicates the (dis) similarity/distance between two students/clusters. The hierarchical tree was cut in order to partition the data into clusters (red for Cluster 1 and blue for Cluster 2).

A similar behavior in the data grouping was observed for all indexes, which indicated that joint mobility accounts for the variation in the data. In fact, the comparison between clusters revealed significant differences in age, body mass, BMI, GIJM, IMVI, IJVI and DPVI while any significant difference was found in stature, FEVI and BSVI (Table 3).

Table 3.
Characteristics of the participants grouped by clusters.

Variable	Cluster 1 (*n*=182)	95% IC (min, max)	Cluster 2 (*n*=57)	95% IC (min, max)	*p*-value
Age (years)	21.0 (2.8)	20.6 – 21.4	24.5 (6.5)	22.8 – 26.3	<.001
Body mass (kg)	62.2 (7.2)	61.2 – 63.3	74.9 (7.4)	72.9 – 76.8	<.001
Stature (cm)	169.7 (7.3)	168.6 – 170.8	171.6 (6.2)	169.9 – 173.2	.177
BMI (kg·m^{-2})	21.6 (1.9)	21.3 – 21.9	25.4 (2.3)	24.8 – 26.0	<.001
GIJM	48.3 (5.7)	47.5 – 49.2	43.8 (5.2)	42.4 – 45.2	<.001
IMVI	0.65 (0.1)	0.63 – 0.67	0.57 (0.09)	0.54 – 0.59	<.001
IJVI	0.41 (0.1)	0.39 – 0.43	0.33 (0.08)	0.31 – 0.36	<.001
FEVI	1.11 (0.1)	1.09 – 1.13	1.12 (0.1)	1.08 – 1.15	.927
BSVI	1.10 (0.1)	1.08 – 1.13	1.06 (0.1)	1.03 – 1.09	.068
DPVI	1.05 (0.1)	1.03 – 1.07	1.09 (0.1)	1.06 – 1.13	.017

Data are expressed as media (SD). *p*-value for the Mann–Whitney U test.

Discussion

The purpose of this study was to evaluate the joint mobility in undergraduate students of a physical education major. The joint mobility indices assessed in our study give information about the flexibility condition of the participants. As we hypothesized, these majors showed a high relative frequency of the high joint mobility categorization (GIJM ≥ 51). Similar to previous reports (Araújo, 2008b; Medeiros et al., 2013; Quatman et al., 2008), the results of the GIJM showed that wo had higher joint mobility and ROM than men. We also assessed the profile of ROM for the individual movements of the Flexitest battery as recommended (Brito et al., 2013). Regarding the IMVI, most proportion of the Physical Education students were categorized as normal, albeit 23% of the men participants showed atypical low values. High values of this index might be due to: i) repeated sports practice as reported previously in martial artists (Marinho et al., 2011), ii) hypermobility, or iii) sport-related injuries (Brooks et al., 2005; Pinedo, 2012). Conversely, 29% of the women participants were categorized in low FEVI indicating a greater joint mobility in the extension movements compared to the flexion ones. More research is warranted in this regard to explore the impact of muscle tone in the evaluated body regions besides the physical activity level (Payne & Isaacs, 2017). Additionally, BSVI (an index which compares upper versus lower limbs) was significantly different when contrasting men and women participants. In fact, 34% of women undergraduates had higher joint mobility in the lower limbs in regards to the upper body segment. This could be due to a muscle dimorphism of both lower musculoskeletal mass and/or lower muscle tone in the lower limbs. Another possible explanation are the anatomical differences between men and women in the structure of the pelvis and the musculature of the pelvic floor (Hricak, 1986; Klutke et al., 1990). Significant differences were found between men and women in the DPVI which revealed that women presented more joint mobility in the proximal joints (hip and shoulder) in comparison to men.

It is worth noting that sex-dependent characteristics in the muscle fascia and its insertion (the tendon) might possibly account for the differences (Edama et al., 2017; Lohr et al., 2020). The sex-based differences in skeletal muscle and connective tissue characteristics allow to adapt and distribute the intensity of the mechanical strains differently (Rey et al., 2016; Rodríguez et al., 2008). The response of these modifiable characteristics after specific training regimens has been revised in previous studies (Farinatti et al., 2014; Simão et al., 2011). It has been proposed that differences in the molecular structure of mucopolysaccharides might influence the impact absorption and resistance to the deforming strains, mainly because of the viscoelastic properties that contribute to friction reduction, lubrication and protection of the tendon (Abate et al., 2009; Roberts, 2016). Notwithstanding, more studies are needed to elucidate molecular structural differences in the evaluated population and the clinically relevant association to joint mobility.

We also used unsupervised machine learning (hierarchical clustering) to subdivide the obtained data into clusters to identify natural groupings and extract profile patterns. Two clusters were obtained with particular differences in terms of joint mobility indexes (see Table 4) which indicates that joint mobility explained the variation in the data (Cluster 1 > Cluster 2). Interestingly, ≈95% of the women participants (37/39) were grouped in the Cluster 1 which is in accordance with the sex-based differences found in our study and discussed previously. The natural grouping (matching) of the clusters was less sensitive to variations in the academic semester of the students which might be interesting to evaluate in future comparisons. Thus, two significantly different phenotypes were identified representing younger, lighter, and more flexible (Cluster 1) versus older, heavier, and less flexible students (Cluster 2). It needs to be noted that a previous clustering-based characterization of Colombian undergraduate population has identified a higher prevalence of high-adiposity, endo-mesomorph and less physically active individuals (Bonilla et al., 2020). Since joint mobility is related to morphological and functional features (e.g., an excess of body fat limits the ROM in some joint movements) (Araújo, 2004), further research is needed to report joint mobility and the influence/associations with other aspects such as body composition, morphological indexes, physical fitness, quality of life, and academic success in this undergraduate population.

Limitations

Our study has certain limitations that should be considered when drawing practical inferences and setting future research. First, the small sample size of women population belonging to the physical education major makes difficult to analyze this subgroup by ranges of ages or academic semester. Second, the undergraduate population is generally very diverse regarding age, body composition and physical activity level which still informative but has shown to affect the analysis of the data and set groups for study interventions. We did not record variables of body composition, physical fitness or academic success which makes necessary more research to find data associations with joint mobility. Third, the possible bilateral differences that are presented in specific conditions (e.g., infra or overuse, after muscle tendinous lesion or any pathology) were not considered due to assumption of participation of healthy individuals. Fourth, observational studies cannot be used to demonstrate causality; therefore, future experimental studies are needed to evaluate the effect of modifying variables that explained most of the variation in our clusters. Finally, although several other tests to evaluate flexibility/joint mobility exist, it is noteworthy to mention that the Flexitest has shown easiness of application, reliability (intra- and inter-observer), and no need of equipment or large space to perform it (Araújo, 2008b; Medeiros et al., 2013). In addition, there are no ceiling nor floor effects that are often seen with other joint mobility tests (e.g., the Beighton-Horan joint laxity test) (Brito et al., 2013).

Interpretation and Generalizability

This observational study not only provides information regarding joint mobility and potential variables that account for data variation but also contributes with methodological procedures to analyze data under the machine learning paradigm and rationale for future research. This data also contributes to identify the need to incorporate flexibility (and fitness) activities into University and even elementary or high-school curriculum. On the other hand, most of the population that participated in this study was categorized as high and medium-high in terms of joint mobility. Although it has been reported that having high joint mobility can provide the ability to sit and rise properly (Brito et al., 2013), readers should be concerned about the lack of data to link the identified cluster-based phenotypes with physical fitness, quality of life (including ADL) and/or academic success. The relative absence of students' homogeneity per major programs does not allow to extend generalizability to other undergraduate populations.

Conclusions

The evaluation of joint mobility in Physical Education majors revealed significant sex-dependent differences. In general, women participants showed higher joint mobility than men while some body segments uncovered joint mobility deficit or hypermobility. This aspect is also observed when comparing standardized joint limitations on ankle, knee, hip, trunk, elbow and shoulder joints. Therefore, the homogeneity profile of range of motion in IMVI, IJVI and FEVI indices without reflecting gender differences, contrary to found in BSVI and DPVI indices. Furthermore, two phenotypes were obtained from our hierarchical clustering analysis which provides relevant information about the particular differences in terms of joint mobility between these undergraduate students. The results of this study could help universities offering this undergraduate curriculum to reinforce regular physical training programs to reduce joint mobility limitations or make decisions about interventions to optimize them. More research is needed to assess associations with general fitness, quality of life, and academic success.

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Disclosure statement

The authors declare not to have any conflict of interests.

Supplemental online material

Table S1 was uploaded and stored under a Creative Commons license in Figshare (https://figshare.com/s/52daefa3a5cd4548b5b2).

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