The ulnar variance phenomenon in Portuguese female and male gymnasts.

A multi-thematic approach studied by a cross-sectional and longitudinal design.


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**KEY-WORDS:** ARTISTIC GYMNASTICS, ULNAR VARIANCE, GYMNASTS, MATURES, IMMATURES, WRIST.
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Rita, Inês and Teresa,
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ABREVIATIONS

AG Artistic Gymnastics
AGDP Age Group Development Program
BMI Body Mass Index
CI Confidence Interval
cm centimeters
DIDI distal point of the ulnar to the distal point of the radial
F.I.G International Gymnastics Federation
FFM Fat-Free Mass
FPG Federação Portuguesa de Ginástica
h/sem horas por semana
h/w hours per week
Kg kilograms
kg/m²
mm millimetres
MRI Magnetic Resonance Imaging
n sample size (number)
OR Odds Ratio
P percentil
p significance
PASW Predictive Analytics Software
PRPR proximal point of the ulnar to the proximal point of the radial
r correlation
R intraclass correlation coefficient
SD Standard Deviation
TW Tanner-Whitehouse
UV Ulnar Variance
yr year
α Alfa index
η² Eta Squared
χ² Chi-square
% fat percentage of body fat
RESUMO

A variância cubital (VC) é caracterizada pela diferença de comprimento relativo das superfícies distais do rádio e cúbito, e tem sido associada à dor e a alterações morfológicas no punho dos ginastas. **Objetivos:** Esta dissertação, constituída por um artigo de revisão e quatro experimentais, pretendeu: (i) analisar a VC nos ginastas e na população em geral (estudo 1); (ii) analisar transversalmente a relação entre a VC e um conjunto de características biológicas e de treino, a força de preensão e a dor em ginastas Portugueses do sexo feminino (estudo I) e masculino (estudo II); (iii) determinar os fatores associados à dor no punho (estudo III); (iv) estudar os ginastas ao longo de 18 meses e verificar se a idade e o treino interferem na VC (estudo IV). **Métodos:** Foram observados 77 atletas (40 femininos e 37 masculinos) de competição de Ginástica Artística (13.6±5.0 anos), entre os quais 56 com imaturidade óssea. Para avaliação da maturidade óssea e da VC foram utilizadas radiografias da mão e punho. Uma balançaanalógica e um estadiómetro foram utilizados na caracterização antropométrica e a composição corporal e a percentagem de gordura corporal foram obtidas através da impedância bioelétrica. A força de preensão foi avaliada através de um dinamómetro mecânico e os dados referentes à dor e características do treino através de entrevista. **Resultados:** Os ginastas têm maioritariamente valores negativos de VC. Nas ginastas femininas a VC está associada à idade óssea, estatura e massa isenta de gordura, e não às restantes características biológicas nem ao treino (estudo I). Nos ginastas masculinos verifica-se uma associação entre a VC e a força de preensão e os anos de prática (estudo II). Não se observaram diferenças significativas entre os valores da VC nos punhos dolorosos e os assintomáticos (estudo II). Quando se avalia os fatores de risco no aparecimento de dor nos ginastas, apenas a idade é um fator determinante nesta sintomatologia (estudo III). Durante um período de treino de 18 meses, a VC altera-se tornando-se menos negativa ou neutra (estudo IV). **Conclusão:** Este estudo sugere que a alteração da VC poderá depender da idade e remete para futuros estudos a influência do treino ou das características biológicas dos ginastas.

**PALAVRAS-CHAVE:** GINÁSTICA ARTÍSTICA, GINASTAS, PUNHO, VARIÂNCIA CUBITAL, DOR.
ABSTRACT

Ulnar Variance (UV) is characterized by differences in the length of distal extremities of radius and ulna and has been related to pain and morphologic changes on gymnasts' wrist. **Aims:** This thesis includes one review article and four experimental papers aiming: (i) to analyze UV in both gymnasts and in the general population (study 1); (ii) to observe the association between UV and a set of biological and training characteristics, and also handgrip strength and pain in a group of Portuguese female (study I) and male gymnasts (study II); (iii) to identify related factors to the wrist pain (study III); (iv) to follow up a group of gymnasts during 18 months in order to analyze if age and training characteristics interfere with UV (study IV). **Methods:** 77 artistic gymnasts (13.6±5.0 years) were observed (40 female and 37 male), among which 56 skeletally immature. To assess skeletal maturity and UV, radiographs from hand and wrist were used. An analogical scale and a stadiometer were used in the anthropometric characterization, while body composition and percentage of body fat were measured through bioelectrical impedance. Handgrip strength was evaluated using a mechanical dynamometer and data related to pain and training characteristics were obtained through an interview. **Results:** Gymnasts, on average, mostly presents negative values of UV. In female gymnasts UV is related to the skeletal age, height and free fat mass and not with biological or training characteristics (study I). We found an association between UV and both handgrip strength and years of training in the male gymnasts (study II). No significant differences were observed in UV values when comparing painful versus asymptomatic wrists (study II). When evaluating the risk of pain onset in gymnasts, only age seems to be a determinant factor in this symptomatology (study III). After 18 months of training the UV becomes less negative or neutral (study IV). **Conclusion:** This study suggests that UV changes may be related to age and future studies are needed to observe the influence of training or gymnasts' biological characteristics.

**KEY-WORDS:** ARTISTIC GYMNASTICS, GYMNASTS, WRIST, ULNAR VARIANCE, PAIN.
RESUME

La variance cubitale (VC) est caractérisée par la différence de longueur relative des surfaces de la partie distale du radius et du cubitus, et a été associée à des douleurs et des modifications morphologiques au niveau du poignet des gymnastes. **Objectifs:** Cette dissertation, composée d’une revue de littérature et de quatre études expérimentales, a eu pour objectifs: (i) analyser la VC chez des gymnastes et dans la population en général (étude 1); (ii) étudier la relation entre la VC et les caractéristiques biologiques, l’entraînement, la force de préhension et de la douleur chez les gymnastes portugaises du sexe féminin (étude I) et du sexe masculin (étude II); (iii) déterminer les facteurs associés à la douleur au poignet (étude III); (iv) étudier les gymnastes sur 18 mois et vérifier si l'âge et l’entraînement interférent avec le VC (étude IV). **Méthodes:** Nous avons observé 77 athlètes (40 filles et 37 garçons) de compétition de Gymnastique Artistique (13,6 ± 5,0 ans), dont 56 à immaturité osseuse. Pour l'évaluation de la maturité osseuse et VC nous avons utilisé des radiographies de la main et du poignet. Une balance analogique et une toise ont été utilisées pour la caractérisation anthropométrique et la composition corporelle et pourcentage de graisse corporelle ont été obtenus par l’analyse d’impédance bioélectrique. La force de préhension a été évaluée à l'aide d'un dynamomètre et les données concernant la douleur et les caractéristiques mécaniques de l’entraînement par le biais d’une entrevue. **Résultats:** Les gymnastes ont présenté, en moyenne et majoritairement, des valeurs négatives de la VC. Chez les gymnastes féminines, la VC est associée à l'âge osseux, à la hauteur et à la masse maigre, et pas aux autres caractéristiques biologiques ou à l'entraînement (étude I). Chez les gymnastes masculins on observe une association entre la VC et la force de préhension et les années d’entraînement (étude II). Il n’y avait pas de différences significatives entre les valeurs de la VC dans les poignets douloureux et les asymptomatics (étude II). Lorsque l’on évalue les facteurs de risque dans l’apparition de douleur chez des gymnastes, seul l’âge est un facteur déterminant dans cette symptomatologie (étude III). Il y a un changement dans la VC sur une période de 18 mois d’entraînement, la VC devenant moins négative ou neutre (étude IV). **Conclusion:** Cet étude suggère que les changements de VC peuvent dépendre de l’âge et remets pour de futures études l’influence de l’entraînement ou des caractéristiques biologique des gymnastes. **MOTS-CLES:** GYMNASTIQUE ARTISTIQUE, GYMNASTE, POIGNET, VARIANCE CUBITALE, DOULEUR.
GENERAL INTRODUCTION

Artistic Gymnastics (AG) demands a high level of performance which requires that gymnasts begin their practice and specialization at very early ages, before bone maturation (Caine, DiFiori, & Maffulli, 2006; DiFiori, Caine, & Malina, 2006; DiFiori & Mandelbaum, 1996) with a relatively rapid transition to high-volume and high-impact training (Caine & Nassar, 2005; Daly, Bass, & Finch, 2001), requiring long hours of practice and repetitive movements (Dwek, Cardoso, & Chung, 2009), as well as high levels of strength, flexibility and balance (Zetaruk, 2000).

According to several authors, the immature musculoskeletal system submitted to repetitive biomechanical stress becomes more vulnerable and may lead to overuse injuries (Cornwall, 2010; Kerssemakers, Fotiadou, de Jonge, Karantanas, & Maas, 2009; Zetaruk, 2000), essentially during the adolescent growth spurt (Caine et al., 2006; Daly et al., 2001; DiFiori et al., 2006; DiFiori, Puffer, Aish, & Dorey, 2002a).

AG is unique among all athletic sports concerning the load it places on the upper extremities (Markolf, Shapiro, Mandelbaum, & Teurlings, 1990) and it requires the conversion of upper limb into load-bearing extremities, leading to upper extremity injuries (Caine, Roy, Singer, & Broekhoff, 1992; Claessens, Lefevre, Philippaerts, Thomis, & Beunen, 1997; Webb & Rettig, 2008), making the wrist growth plates a potential site for injuries (Caine et al., 2006; DiFiori et al., 2006; DiFiori, et al., 2002a) and creating high incidence of pain (Amaral, Claessens, Ferreirinha, Seabra, & Santos, 2012d; DiFiori, 2006; DiFiori, et al., 2006; Dwek, et al., 2009; Webb & Rettig, 2008).

Wrist pain is a major problem for adolescent gymnasts, both boys and girls (Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2006; DiFiori et al., 2002a), which may influence their performance in training and/or competition and promote the loss of training days or the reduction in the number of repeats for training session (Caine et al., 1992; DiFiori et al., 2006; Roy, Caine, & Singer, 1985). These painful symptoms in gymnasts are often viewed as the result of epiphyseal trauma and related changes caused by repetitive loads, mainly on
General Introduction

the distal end of the radius as its interface with the carpals (Caine et al., 2006; DiFiori et al. 2006), inhibiting normal growth of the radius and resulting in positive ulnar variance (UV), which is a specific characteristic of AG (Caine et al. 2006; Caine, Lindner, Mandelbaum, & Sands, 1996; Chang et al., 1995; De Smet, Claessens, Lefevre, & Beunen, 1994; DiFiori et al., 2006; DiFiori, Puffer, Mandelbaum, & Dorey, 1997; Dwek et al., 2009; Mandelbaum, Bartolozzi, Davis, Teurlings, & Bragonier, 1989).

UV refers to the relative positioning of the distal end of the ulna relative to the distal end of the radius (Hafner, Poznanski, & Donovan, 1989; De Smet, 1994; DiFiori et al., 2006; Schuurman, Maas, Dijkstra, & Kauer, 2001; Webb & Rettig, 2008). When the length of the distal ulna exceeds the length of distal radius by 1 mm or more, UV is considered positive or labelled as 'ulnar overgrowth', and it is negative when the length of the distal ulna is less than the length of distal radius by 1 mm or more (Hafner et al., 1989; Palmer, Glisson, & Werner, 1982). When the relative length of the distal radius and ulna differ by less than 1 mm, UV is labelled as 'neutral' (De Smet, 1994; DiFiori et al., 2006). The small changes in UV have a direct relationship with the magnitude of load-bearing (Sönmez, Turaclar, Tas, & Sabanciogullari, 2002). Changes in UV under 1 mm can alter mechanical transfer of the load characteristics by more than 25% and probably have particular clinical significance in individuals who perform repetitive rotational manoeuvres with load on the wrist, as in sports like gymnastics (Mann, Wilson, & Gilula, 1992; Yoshioka et al., 2007). The load on the neutral UV wrist is normally shared between radius and ulna in a ratio of approximately 80:20 (Anderson, Read, & Steinweg, 1998). The load distribution in the positive UV wrists is, on average, 69% and 31%, and in negative UV wrists the load distribution ranges, on average, between 94% on the radius and 6% on the ulna (Bu, Patterson, Morris, Yang, & Viegas, 2006).

Although the reference children and adolescents present typically negative values of UV (Chang et al., 1995; Hafner et al., 1989), becoming somewhat more negative with increasing age, when compared to the results gathered on gymnasts it can be observed a wide range of UV results (Claessens, Lefevre, Beunen, De Smet, & Veer, 1996; Claessens, Moreau & Hochstenbach, 1998). Despite the prevalence of negative UV values in immature gymnasts, there are
several reports showing greater incidence of relative and absolute positive UV in the gymnasts’ samples when compared with reference samples or control groups. These more positive UV values are within the normal range for their age but at the upper limit (Claessens et al., 1996).

However, in general all studies performed on mature gymnasts demonstrated a positive mean value for UV (Chang et al., 1995; Jung, Baek, Kim, Lee, & Chung, 2001; Mandelbaum et al., 1989; Sönmez et al., 2002; Yoshioka et al., 2007), while some data on mature reference populations show, on average, mostly negative and neutral UV values (Ertem, Kekilli, Karakoç & Yologlu, 2009; Freedman, Edwards, Willems, & Meals, 1998; Schuind, Linscheid, An, & Chao, 1992; Unver, Gocen, Sen, Gunal, & Karatosun, 2004; Yeh, Beredjiklian, Katz, Steinberg, & Bozentka, 2001).

Supposing that wrist load contributes to changes on UV, some variables such as training and biological characteristics may be related with its values. Several studies suggest that gymnastics training, with significant volume and intensity of load may precipitate abnormal changes of the distal radial growth plate and eventually lead to premature physeal closure and consequent positive UV (Chang et al., 1995; DiFiori et al., 2002a; Mandelbaum et al., 1989; Caine et al. 1992). For this reason, it is predictable that the dominant hand presents higher positive UV due to the heavier load (Claessens et al., 1998) and that UV may be affected by handgrip strength (Sönmez, et al., 2002) or flexibility/range of motion (Unver et al., 2004). To others, gymnasts who are taller, heavier, with higher muscular mass or with a high percentage of body fat, tend to present more positive UV (Claessens et al., 1996; Caine et al., 1992; O’Connor, Lewis, & Boyd, 1996). To Emery (2003), this condition seems to appear due to the high forces absorbed by the musculoskeletal system.

On the other hand, other authors didn’t find any significant association between training characteristics and UV, showing that AG training does not have a direct negative impact on UV (De Smet et al., 1994; Claessens et al. 1996; DiFiori et al. 1997; Claessens, 2003; Amaral, Claessens, Ferreirinha & Santos, 2012a). According to Chang et al. (1995), the presence or absence of damage on the
gymnast’s wrists may depend on the balance between adequate and excessive stress of the activity and on the relationship between the radius and ulna.

The referred results were not conclusive because diverse trends have been noted in different studies of skeletally immature and mature gymnasts, so the real influence of specific characteristics of gymnastics training on the UV phenomenon is not yet known. For this reason, in our opinion it is very important to identify the predisposing risk factors for: (i) the wrist pain; (ii) the change in the relative length of the distal extremities of the ulna and radius; (iii) the changes in the skeletal morphology; (iv) the inhibition of the normal growth of the distal physis.

Because most of the studies on this subject were performed using a cross-sectional design which do not allow the establishment of a cause-effect relationship, longitudinal and intervention studies are needed, in which gymnasts are followed for several years and thus the dose-response relationship between gymnastics training and UV could be studied in a more effective way.
CHAPTER I
AIMS
AIMS

The main purposes of this study were: (a) to summarize the current literature on the subject of UV and to describe its trends, taking into account its association with some biological and/or training variables; (b) to analyze the incidence of positive, neutral and negative UV among gymnasts and in the general population (both immature and mature), seeking to identify possible wrist injury risk factors, which usually influence the gymnasts’ health and performance. To attain these general goals, specific purposes were designed for each of the original articles presented throughout this dissertation.

Paper I

To investigate the UV in a group of Portuguese skeletally immature female gymnasts of different age and skill level: (i) the relationship between UV and some biological and training characteristics; (ii) the left-right UV differences between wrists.

Paper II

To investigate the UV in a group of Portuguese skeletally immature male gymnasts of different age and skill level: (i) the relationship between UV and some biological and training characteristics; (ii) the wrist pain status in relation to UV.

Paper III

To analyze the determinants of wrist pain in Portuguese gymnasts: (i) to detect the groups of higher risk.

Paper IV

To investigate the variability and changes of UV in Portuguese’s immature artistic gymnasts followed during a period of 18 months: (i) to observe how UV evolves with age and training characteristics; (ii) to understand if different UV categories (positive, neutral or negative) react differently to training
Aims

characteristics; (iii) to analyze the relationship between UV and some biological and training characteristics.

This thesis is based on the following review and original articles (referred in text by Arabic and Roman numbers):

THEORETICAL BACKGROUND


EXPERIMENTAL WORK


CHAPTER II

THEORETICAL BACKGROUND
Review Article

Ulnar variance and its related factors in gymnasts: A review

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Running Head: Ulnar variance in gymnasts

Keywords: gymnastics, morphology, wrist, injury.

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ABSTRACT
Ulnar variance is the relative length of ulna in relation to the radius. This morphological variation in the distal epiphyseal structures may lead to symptoms or pathologic changes to the wrist joint. In order to evaluate and quantify distal radioulnar length discrepancy, different imaging techniques are used, depending on the individual's maturity. The purpose of this review is to summarize the current literature on this subject and to describe ulnar variance trends, taking into account its association with biological and/or training precursors. Our study analyzes the incidence of positive, neutral and negative ulnar variance between gymnasts and the general population (both immature and mature), seeking to identify possible wrist injury risk factors, which usually influence the gymnasts' health and performance.
1. INTRODUCTION

Artistic Gymnastics (AG) demands a high level of performance which requires that gymnasts begin their practice and specialization at very early ages, before bone maturation (Caine et al., 2006; DiFiori et al., 2006; DiFiori & Mandelbaum, 1996). Based on results from biomechanical studies of the physis, the vulnerability for growth plate injuries is higher during the adolescent growth spurt (Caine et al., 2006; Daly et al., 2001; DiFiori et al., 2006; DiFiori et al., 2002a). During this period, the injury risk may increase due to the weakness in the transition area of the cartilage’s hypertrophic cell junction and the area of the calcification matrix in the metaphyseal side of the growth plate (Caine et al., 1992; DiFiori & Mandelbaum, 1996).

One of the specific training characteristics in AG is the alternation of support between upper and lower limbs, with the upper extremities often used for weight-bearing therefore, receiving high impacts in both the elbow and wrist (Caine, 2003; Claessens et al., 2003; Daly et al., 2001; DiFiori et al., 2006; DiFiori et al., 2002a). So, with the early beginning of specialized training the growth plate in gymnasts’ wrists becomes a potential place for injuries (DiFiori et al., 2006; DiFiori et al., 2002a). These different types of stress, which include axial compression, rotation and distraction forces (Webb & Rettig, 2008) may exceed twice the body weight of the gymnast (Koh, Grabiner & Weiker, 1992). Events such as pommel horse, floor exercise, vault, and balance beam include many skills which expose the wrist joint to repeated loads with relatively large static and dynamic forces (DiFiori et al., 2006). Many of gymnastics’ skills cause an extraordinary stress on the distal growth plates of radius and ulna, on the carpal bones of the hand and on many ligaments that stabilize these structures (Dwek et al., 2009).

Actually, gymnasts of both genders have frequent wrist pain (DiFiori et al., 2006), which may influence their performance in training and/or competition, leading to the reduction of the number of repetitions in training sessions and lost training days (Caine et al., 1992; DiFiori et al., 2006; Roy et al., 1985). Several
authors (Caine et al., 1996; De Smet et al., 1994; Roy et al., 1985) relate stress changes of the distal radius to epiphyseal traumas and supports that in AG (particularly female athletes) the repetitive loads in the immature wrist may result (besides wrist pain) in partial interruption of distal radial growth plate and subsequent development of positive ulnar variance (UV) during bone maturation. Alternatively, it has been suggested that the positive UV observed on gymnasts may result from individual characteristics (Claessens et al., 1996), and in part genetically influenced (Beunen, Malina, Claessens, Lefevre & Thomis, 1999; Cerezal et al., 2002).

The aim of this article is to review the literature concerning the UV phenomenon showing the related factors, the main research information on the subject, as well as its connection to the practice of AG. Knowledge about the different factors that may exacerbate the UV and predispose some gymnasts to wrist pain might help to prevent injuries and improve gymnastics performance.

2. METHODOLOGY

2.1. Data sources and searches

The following databases were searched: Medline journals from 1969 to January (week 1) 2011. The combinations of key words entered with Boolean operators were: ulnar variance ‘AND’ gymnast ‘AND’ mature (n=3, excluded 2); ulnar variance ‘AND’ ‘NOT’ gymnast ‘AND’ mature (n=3, excluded 2); ulnar variance ‘AND’ gymnast ‘AND’ immature (n=8, excluded 4); ulnar variance ‘AND’ ‘NOT’ gymnast ‘AND’ immature (n=89, excluded 88). Additionally the combinations ulnar variance ‘AND’ gymnast wrist ‘OR’ wrist pain, anthropometric characteristics, hand strength, dominance, handedness, laterality ‘OR’ measurement, were used. The total number of studies found about ulnar variance was 644. All other references were obtained through citations (from bibliographies of the retrieved articles). If any additional study-specific components or parameters were reported, they were also listed.
2.2. Selection of studies

Inclusion criteria were: 1) Primary sources published in English peer-reviewed journals that included data related to UV values and measurement in mature or immature humans; 2) males and females; 3) subjects without clinically diagnosed osteoarticular or rheumatologic pathology and not submitted to any surgery; and 4) intrinsic and extrinsic factors related to UV.

Exclusion criteria were: 1) review articles or secondary sources to eliminate potential bias; 2) not full text; 3) case reports; 4) books; 5) articles unrelated; 6) alterations only in radial growth; and 7) injury/peripheral neuromuscular pathologies or fractures.

Our review of the literature exposed 8 cross-sectional studies and 3 cohort studies (one retrospective, one prospective and one mixed-prospective) with relevant data on immature gymnasts, and 2 cross-sectional studies and 1 prospective cohort on mature gymnasts.

Related to the general population, 11 cross-sectional studies were revealed, 3 prospective cohort studies and no randomised controlled study was found. Studies described UV values, method of data collection, sample and some factors or conditions which may influence UV such as anthropometric and training characteristics.

Each article was reviewed looking for information about UV and its relation with biological and training characteristics. Through these data we seek to increase the knowledge about the effects and risks of gymnastics practice on the alterations of distal growth plates from radius and ulna and to know if there was compromised development. The data from the gymnastics’ population was related to the general population.

3. FINDINGS

3.1. The concept of ‘ulnar variance’

The concept of UV or the radioulnar index, refer to the relative difference in length between radius and ulna and have been well described since the beginning of the 20th century (Schuurman, Maas, Dijkstra & Kauer, 2001).
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Ulnar variance in gymnasts

Caine, Howe, Ross & Bergman (1997) preferred a different terminology using the term 'ulna-radial length difference'.

Cited by Schuurman et al. (2001), Hultén introduced in 1928 the expressions of variation 'ulnar plus' and 'ulnar minus' in order to describe the length of the ulna relative to the length of the radius. When the length of the distal ulna exceeds the length of distal radius by 1 mm or more, UV is considered positive or labelled as 'ulnar overgrowth', and it is negative when the length of the distal ulna is less than the length of distal radius by 1 mm or more (Hafner et al., 1989; Palmer et al., 1982). When the relative length of the distal radius and ulna differ by less than 1 mm, UV is labelled as 'neutral' (De Smet, 1994; DiFiori et al., 2006). The variance is independent of the length of the ulnar styloid process (Cerezal et al., 2002).

The length of the ulna relative to the length of the radius (expressed by UV) is not constant but varies in the course of life (De Smet, 1994) and may be affected by daily activities involving repetitive forearm movements (Cerezal et al., 2002; Tomaino, 2000). Several authors (Freedman et al., 1998; Schuurman et al., 2001; Sönmez et al., 2002) mention differences in length between radius and ulna during static (unloaded) and dynamic (loaded) evaluation leading to towards a significant increase in positive UV. UV affects the forces' distribution across the wrist (Webb & Rettig, 2008), and for this reason can be an important feature of wrist disorders or ‘pathological’ wrist (De Smet, 1994), since the percentage of load suffered by the distal epiphysis of the radius increases with a shorter ulna (DiFiori et al., 2002a). The load on the neutral UV wrist is normally shared between radius and ulna in approximately an 80:20 ratio (Anderson et al., 1998) and this ratio changes with the increase or decrease of UV values. In a biomechanical evaluation concerning force distribution on the wrist joint, Bu et al. (2006) verified that the load distribution between ulna and radius in the positive UV wrists was, on average, 69% and 31%, respectively. In the negative UV wrists the load distribution ranged on average between 94% on the radius and 6% on the ulna.

Several pathological conditions are correlated with negative UV, namely the carpal instability, ulnar subluxation of the carpals, avascular necrosis of the scaphoid and scapholunate dissociation (De Smet, 1994). Nishiwaki,
Nakamura, Nakao, Nagura & Toyama (2005) have reinforced the possibility that higher values of negative UV are associated with increased pressure over the distal radio-ulnar joint and a greater probability of degenerative alterations. In this context, it seems reasonable that wrists with high levels of negative UV present a higher prevalence of pain and abnormal radiographic signs in the distal radial growth plate (DiFiori et al., 2002a). On the other hand, the positive UV in gymnasts may increase the ulnar carpal loading (Palmer et al., 1982), or contribute to the ulnar impact syndrome, degenerative injuries, cartilaginous wear of carpal bones, rupture of the triangular fibrocartilage complex and osteomalacia of the ulnar carpals (Anderson et al., 1998; Cerezal et al., 2002; De Smet, 1994; Yoshioka et al., 2007).

Other deformities caused by the repetition of micro-traumas in the epiphysis before skeletal maturity may lead to the premature closure of the growth plate (De Smet, 1994) and stress injuries of the physis may lead to permanent sequels, even in asymptomatic individuals (Chang et al., 1995). The radial and palmar inclination of the distal articular radial surface transmits a vertical compression force into the palmar-ulnar sector, creating high compression and premature closure of the palmar-ulnar part of the physis (De Smet, 1994). Similar changes take place in the ‘Madelung-like deformity’, an irregularity in the development of the wrist, characterized by anatomical changes in the radius, ulna and carpal bones. Radiographic findings reveal increased dorsal and radial bowing of the distal radius, triangular-shaped carpus, exaggerated volar and ulnar tilt of the distal articular radial surface, positive UV (Arora & Chung, 2006; Brooks, 2001; Zebala, Manske & Goldfarb, 2007) and even ulnopalmal subluxation of the carpus (Brooks, 2001; De Smet, 1994).

In the context of AG, De Smet, Claessens & Fabry (1993) have referred to this situation as the ‘gymnast wrist’, or ‘Madelung-like deformity’. In a case study involving a female gymnast, Brooks, (2001) used this latter expression due to its similar appearance to the relatively uncommon developmental malformation (2% of the general population), although it was a case involving traumatic ethiology. Dwek et al. (2009) recommended that, the term ‘gymnast wrist’,

Ulnar variance in gymnasts

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usually associated with a chronic physeal trauma, should be enlarged to include nonphyseal osseous, ligamentous and osteochondral injuries.

### 3.2. Measurement of ulnar variance: technical concerns

Since the epiphyses of children are not yet completely ossified, the techniques to measure UV have to be different from those used in adults, requiring a specific method demanding different criteria of measurements (De Smet, 1994; Hafner et al., 1989; Palmer et al., 1982).

The evaluation of UV in immature wrists is done through radiological measures of the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis (PRPR) and of the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis (DIDI), according to Hafner’s method (Hafner et al., 1989). In order to minimize measurement errors, it is possible to draw a medial parallel line to the ulna axis and delineate two perpendicular lines, one touching the most proximal point and the other the most distal point of the distal ulnar metaphysis, as well as the two lines corresponding to the same points in the radial metaphysis (Claessens et al., 1996; Hafner et al., 1989).

Concerning the evaluation of mature wrists, there are several published methods of measurement which are equally reliable: 1) the ‘Project-a-line’ technique; 2) the Concentric Circles method and modifications (Palmer’s method); and 3) the ‘Perpendicular’- method (Mann et al., 1992).

The ‘Project-a-line’ technique consists in drawing a solid line starting on the ulnar side of the articular surface in the distal radius, measuring the distance between this line and the carpal surface of the ulna (Keats & Sistrom, 2001; Mann et al., 1992).

The evaluation of mature wrists by Palmer’s method is done through an over positioning of a concentric semi-circles model in the x-ray identifying the circle which most approximates the concavity of the distal sclerotic line of the radius. The distance from this line to the cortical rim of the caput ulna is the
measurement used to determine the UV (Keats & Sistrom, 2001; Mann et al., 1992; Palmer et al., 1982).

In the ‘Perpendicular’- method, a line parallel to the long axis of the radius is drawn and a second line which passes through the ulnar notch and perpendicular to the first line. The distance between this second line and the ulna’s head is defined as UV (Keats & Sistrom, 2001; Mann et al., 1992; Sönmez et al., 2002).

According to Schuurman et al. (2001), Palmer’s method is considered to be simple and reliable, however, errors may occur when the pattern model is placed over an imprecise curvature of the distal extremity of the radius. He considers that this method may be perfected with an electronic digitizer connected to a personal computer. The predominance of positive UV was observed using the concentric circles method, although negative when using the digitizer (Schuurman et al., 2001). Steyers and Blair (1989) have compared the referred methods to measure UV, concluding that all were highly reliable, although the ‘Perpendicular’- method was most consistent for both inter and intra-observer reliability.

3.3. Ulnar variance in reference populations and gymnasts

3.3.1. Ulnar variance in immature samples

An overview of UV results in immature reference and gymnasts populations is given in Table 1.
### Theoretical Background

**Ulnar variance in gymnasts**

Table 1 - Cross-sectional and cohort data of ulnar variance measurements in immature reference and gymnasts samples

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample studied</th>
<th>Gender</th>
<th>Mean age (yr)</th>
<th>Type of study</th>
<th>UV method a</th>
<th>Mean UV (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Immature populations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hafner et al. (1989)</td>
<td>535 M+F</td>
<td>2-15 (range)</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR) (DIDI)</td>
<td>-2.1 / -2.3 (range)</td>
<td></td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>38 M+F</td>
<td>13.2</td>
<td>Prospective cohort</td>
<td>Perpendicular</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Immature gymnasts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Smet et al. (1994)</td>
<td>156 F</td>
<td>15.9</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR) (DIDI)</td>
<td>+0.49 / -1.43</td>
<td></td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>176 M+F</td>
<td>13.1</td>
<td>Cross-sectional</td>
<td>Perpendicular</td>
<td>+0.07</td>
<td></td>
</tr>
<tr>
<td>Claessens et al. (1996)</td>
<td>156 F</td>
<td>15.9</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR) (DIDI)</td>
<td>+0.5 / -1.4</td>
<td></td>
</tr>
<tr>
<td>Claessens et al. (1997)</td>
<td>36 F</td>
<td>6-14 (range)</td>
<td>Mixed-prospective</td>
<td>Hafner (DIDI)</td>
<td>-3.4 / -6.5 (range)</td>
<td></td>
</tr>
<tr>
<td>DiFiori et al. (1997)</td>
<td>44 M+F</td>
<td>11.6</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR)</td>
<td>-1.3</td>
<td></td>
</tr>
</tbody>
</table>

(to be continued)
### Table 1 - continued

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Gender</th>
<th>Mean Age (range)</th>
<th>Study Design</th>
<th>Reference Method</th>
<th>Hafner (PRPR-right)</th>
<th>Hafner (PRPR-left)</th>
<th>Hafner (DIDI-right)</th>
<th>Hafner (DIDI-left)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claessens et al. (1998)</td>
<td>36</td>
<td>F</td>
<td>6-14 (range)</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR-right)</td>
<td>-1.6</td>
<td>-0.8</td>
<td>-4.8</td>
<td>-4.9</td>
</tr>
<tr>
<td>DiFiori et al. (2002)</td>
<td>59</td>
<td>M+F</td>
<td>9.3</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR)</td>
<td>-1.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Claessens et al. (2003)</td>
<td>16</td>
<td>F</td>
<td>6-13 (range)</td>
<td>Prospective cohort</td>
<td>Hafner (DIDI)</td>
<td>-3.4/-6.0 (range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwek et al. (2009)</td>
<td>10</td>
<td>F</td>
<td>14.2</td>
<td>Retrospective cohort</td>
<td>Hafner (PRPR) (measured on MRI)</td>
<td>-0.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amaral et al. (2012a)</td>
<td>33</td>
<td>F</td>
<td>11.1</td>
<td>Cross-sectional</td>
<td>Hafner (PRPR-right)</td>
<td>-2.2</td>
<td>-1.7</td>
<td>-3.1</td>
<td>-2.8</td>
</tr>
</tbody>
</table>

*The method Hafner refers to Hafner et al. (1989) / PRPR refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / DIDI refers to the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis / Perpendicular refers to the method described by Steyers and Blair (1989).*
With the exception of the study of Chang et al. (1995) on Chinese boys and girls, in which the 'Perpendicular'- method was used to determine the ulnar variance measurements, in all other studies the method of Hafner et al. (1989) was used so that results from the different studies can be compared.

As demonstrated by the data gathered by Hafner et al. (1989) on American boys and girls, ranging in age from 2 to 15 years, the UV is on average negative. With increasing age UV becomes somewhat more negative, ranging from -2.1 to -2.3 mm for PRPR and from -2.3 to -2.8 mm for DIDI. In Chinese boys and girls, Chang et al. (1995) found a mean negative value of -0.05 mm as measured by the 'Perpendicular'- method.

Comparing the results gathered on gymnasts, it can be demonstrated that a wide range of mean UV results is observed. For PRPR the mean values ranged from -2.2 to +0.50 mm for Portuguese female gymnasts (Amaral et al., 2012a) and international World-top female gymnasts (Claessens et al., 1996) respectively. For DIDI, the mean values range from -1.4 to -4.9 mm for international World level female gymnasts (Claessens et al., 1996) and nonelite Flemish female gymnasts (Claessens et al., 1998) respectively. When compared with the reference samples, it can be stated that despite the prevalence of negative UV values in immature gymnasts, there are several reports showing greater incidence of relative and absolute positive UV in the gymnasts' samples. However, a closer look at the results shows that these more positive UV values are within the normal range for their age, but at the upper end of the scale, as already demonstrated by Claessens et al. (1996) in a sample of international World level female gymnasts.

Since the values of UV in immature gymnasts are typically negative, probably they have a higher predisposition to an increased load on the radius' growth plate which may influence its development.

3.3.2. Ulnar variance in mature samples

An overview of UV results in mature reference and gymnastics populations is given in Table 2.
### Theoretical Background

Table 2- Cross-sectional and cohort data of ulnar variance measurements in mature (fused physis) reference and gymnasts samples

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample studied</th>
<th>UV method</th>
<th>Mean UV (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N  Gender</td>
<td>Mean age (yr)</td>
<td>Type of study</td>
</tr>
<tr>
<td><strong>Mature populations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>25 M+F</td>
<td>15.0</td>
<td>Prospective cohort Musicians (China)</td>
</tr>
<tr>
<td>Freedman et al. (1998)</td>
<td>100 M+F</td>
<td>19-61 (range)</td>
<td>Cross-sectional Volunteer sample (USA)</td>
</tr>
<tr>
<td>Schuurman et al. (2001)</td>
<td>68 M+F</td>
<td>18-65 (range)</td>
<td>Cross-sectional Patients (Netherlands)</td>
</tr>
<tr>
<td>Yeh et al. (2001)</td>
<td>15 M+F</td>
<td>22-46 (range)</td>
<td>Cross-sectional Volunteer sample (USA)</td>
</tr>
<tr>
<td>Jung et al. (2001)</td>
<td>120 M+F</td>
<td>20-35 (range)</td>
<td>Cross-sectional Volunteer sample (Korea)</td>
</tr>
<tr>
<td>Sönmez et al. (2002)</td>
<td>41 M</td>
<td>19-24 (range)</td>
<td>Cross-sectional Volunteer sample (Turkey)</td>
</tr>
<tr>
<td>Unver et al. (2004)</td>
<td>102 M+F</td>
<td>18-24 (range)</td>
<td>Cross-sectional Medical students and nurses (Turkey)</td>
</tr>
</tbody>
</table>

(to be continued)
### Theoretical Background

#### Ulnar variance in gymnasts

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Gender</th>
<th>Range (years)</th>
<th>Methodology</th>
<th>Methodology Details</th>
<th>Hand Position</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoshioka et al. (2007)</td>
<td>29</td>
<td>M+F</td>
<td>27.0</td>
<td>Cross-sectional</td>
<td>Volunteer sample (Japan)</td>
<td>MRI</td>
<td>+0.05</td>
</tr>
<tr>
<td>Chen and Wang (2008)</td>
<td>864</td>
<td>M+F</td>
<td>23-69 (range)</td>
<td>Prospective cohort</td>
<td>Volunteer sample (Taiwan)</td>
<td>Palmer</td>
<td>+0.38</td>
</tr>
<tr>
<td>Ertem et al. (2009)</td>
<td>77</td>
<td>M+F</td>
<td>14-71 (range)</td>
<td>Cross-sectional</td>
<td>Volunteer sample (Turkey)</td>
<td>Perpendicular</td>
<td>Positive: 5.2% Neutral: 75.3% Negative: 19.5% Dominant hand: Positive: 7.8% Neutral: 75.3% Negative: 16.9%</td>
</tr>
</tbody>
</table>

#### Mature gymnasts

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Gender</th>
<th>Range (years)</th>
<th>Methodology</th>
<th>Methodology Details</th>
<th>Hand Position</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandelbaum et al. (1989)</td>
<td>20</td>
<td>M: n=11 F: n=9</td>
<td>18-23 (range)</td>
<td>Cross-sectional</td>
<td>Collegiate champions (USA)</td>
<td>Palmer</td>
<td>Males: +2.82 Females: +1.44</td>
</tr>
<tr>
<td>Mandelbaum et al. (1989)</td>
<td>18</td>
<td>M</td>
<td>19-23 (range)</td>
<td>Cross-sectional</td>
<td>Collegiate sublevel (USA)</td>
<td>Palmer</td>
<td>+1.28</td>
</tr>
<tr>
<td>De Smet et al. (1994)</td>
<td>35</td>
<td>F</td>
<td>17-23 (range)</td>
<td>Cross-sectional</td>
<td>World-top / international</td>
<td>Palmer</td>
<td>+1.9</td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>85</td>
<td>M+F</td>
<td>15.0</td>
<td>Prospective cohort</td>
<td>Chinese opera students</td>
<td>Perpendicular</td>
<td>+1.29</td>
</tr>
</tbody>
</table>

*Perpendicular* refers to the method described by Steyers and Blair (1989) / *Palmer* refers to the method described by Palmer et al. (1982) / *MRI* refers to Magnetic resonance imaging.
Compared to the immature data much more data on mature reference populations are at hand, whereas only a few data sets on mature gymnasts are gathered. Because different techniques are used to measure the UV, comparison of results is not always possible. However, in general all studies performed on mature gymnasts demonstrated a positive mean value for UV, varying from +1.28 to +2.82 mm, respectively for male collegiate nonelite gymnasts and for male collegiate champions (Mandelbaum et al., 1989).

Data on mature reference populations show, on average, mostly negative and neutral UV values (Ertem et al., 2009; Freedman et al., 1998; Schuind, et al., 1992; Unver, Gocen, Sen, Gunal & Karatosun, 2004; Yeh et al., 2001), although some researchs describe small mean positive values (Chang et al., 1995; Jung et al., 2001; Sönmez et al., 2002; Yoshioka et al., 2007).

3.4. Ulnar variance in gymnasts versus control subjects: statistically controlled studies

An overview of UV results in gymnasts statistically compared to control subjects is given in Table 3.
### Theoretical Background

#### Ulnar variance in gymnasts

Table 3 - Overview of ulnar variance in gymnasts versus control subjects: statistically controlled

<table>
<thead>
<tr>
<th>Reference</th>
<th>Gymnasts (G)</th>
<th>Controls (C)</th>
<th>UV - method</th>
<th>UV differences between G and C</th>
</tr>
</thead>
<tbody>
<tr>
<td>n, Gender, Characteristics</td>
<td>n, Gender, Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Immature samples (unfused physis)**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Gender</th>
<th>Characteristics</th>
<th>n</th>
<th>UV differences between G and C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chang et al. (1995)</td>
<td>M+F</td>
<td>Chinese opera students</td>
<td>38</td>
<td>UV method, not significant</td>
</tr>
<tr>
<td>Claessens et al. (1997)</td>
<td>F</td>
<td>Elite Flemish gymnasts</td>
<td>36</td>
<td>UV method, not significant</td>
</tr>
<tr>
<td>DiFiori et al. (1997)</td>
<td>M+F</td>
<td>Nonelite gymnasts (USA)</td>
<td>535</td>
<td>UV method, not significant</td>
</tr>
<tr>
<td>DiFiori et al. (2002)</td>
<td>M+F</td>
<td>Nonelite gymnasts (USA)</td>
<td>535</td>
<td>UV method, not significant</td>
</tr>
<tr>
<td>Dwek et al. (2009)</td>
<td>F</td>
<td>Nonelite gymnasts (USA)</td>
<td>535</td>
<td>UV method, not significant</td>
</tr>
</tbody>
</table>

(to be continued)

29
### Table 3 – continued

#### Mature samples (fused physis)

<table>
<thead>
<tr>
<th>Study</th>
<th>Sex</th>
<th>Count</th>
<th>Group</th>
<th>Age-matched non-athletes</th>
<th>Mean UV</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandelbaum et al. (1989)</td>
<td>M</td>
<td>11</td>
<td>Elite gymnasts (USA)</td>
<td>20 M</td>
<td>+2.82 mm</td>
<td>Palmer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nonelite gymnasts (USA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>18</td>
<td>Elite gymnasts (USA)</td>
<td>5 F</td>
<td>+1.28 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>9</td>
<td>Age-matched non-athletes</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>De Smet et al. (1994)</td>
<td>F</td>
<td>35</td>
<td>World-top / international gymnasts</td>
<td>125 F</td>
<td>+1.9 mm</td>
<td>Palmer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matched non-athletes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>M+F</td>
<td>85</td>
<td>Chinese opera students</td>
<td>25 M+F</td>
<td>+1.29 mm</td>
<td>Perpendicular</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chinese musicians</td>
<td></td>
<td>+0.89 mm</td>
<td>Significant (p &lt; 0.05)</td>
</tr>
</tbody>
</table>
Theoretical Background

Except for the study by Claessens et al. (1997) in which no statistical difference was observed in UV between two groups of female gymnasts, elite compared to recreational gymnasts, in all other studies a significant more positive UV was shown in the groups of gymnasts compared to the control groups. It has been proposed by several authors that the repetitive stress experienced by the skeletally immature wrist during gymnastics training, especially in the young female elite gymnasts, may lead to the development of wrist pain, partial arrest of the distal radial growth plate, and the subsequent development of positive ulnar variance. Thus, this proposal suggests a dose-response relationship involving the closure of the radial growth plate, caused by the gymnastics training load which results in a positive ulnar variance. This line of reasoning is largely based on ‘patients’ or ‘case’-reports, meaning individuals who present themselves to a clinic with wrist pain, and on cross-sectional studies in which a relatively small number of both nonelite and elite gymnasts were studied.

Although, on average, a positive ulnar variance in most studies could be observed, contradictory results and controversial conclusions were made. Also, due to the small sample sizes and selective recruitment, the subjects under study were not necessarily representative of the elite gymnastics population. Also, most of the studies were set up as a cross-sectional design and as such, these designs do not allow establishing a cause-effect relationship. Well-controlled longitudinal studies, in which elite gymnasts are followed for several years, are needed, in which the dose-response relationship between gymnastics training and ulnar variance can be studied in a more effective way. To our knowledge there are only a few longitudinal studies of UV in young gymnasts.

Different trends have been noted in the development of UV in two cohort studies of skeletally immature gymnasts (Claessens et al., 1997; DiFiori, Puffer & Dorey, 2001). In a study by Claessens et al. (1997) in which 36 female gymnasts, aged 6 to 14 years, were annually followed for four or five seasons, with a total of 158 observations, a negative UV was observed that became more pronounced with increasing age, the mean UV varied from -3.4 to -6.5 mm. This finding was unexpected given that UV ordinarily becomes somewhat more positive with age in immature (unfused) wrists as demonstrated by the cross-
sectional data of Hafner et al. (1989). In contrast, DiFiori et al. (2001) observed that a mean negative UV at baseline became significantly more positive than age-appropriate normative values in 28 male and female gymnasts, aged 5-16 years, during a three year follow-up (DiFiori et al., 2006). More longitudinal and intervention studies are needed to unravel the complex UV phenomenon before more exclusive interpretations can be made.

3.5. Factors related with ulnar variance

In order to structure this review with as much consistency as possible, the ulnar variance-related factors were selected based on the relevance given by the literature on this specific matter, which considers intrinsic and extrinsic factors.

As intrinsic factors were considered: a) chronological age and even more importantly the skeletal age due to the relation to the bone morphology; b) morphological and body composition characteristics (weight, height, BMI, % fat, fat-free mass) because differences in these values can be associated to a different in load and biomechanical characteristics of the impacts; c) handgrip strength because UV has a dynamic character and change with the kind of handgrip; d) hypermobility because certain positions of the wrist joint and forearm (pronation/supination, ulnar/radial deviation) modify the UV (more positive or negative), increasing the UV.

As extrinsic consider were observed: a) training, characterized by hours spent in the activity, which supposedly, besides increase the predisposition of the gymnasts to injury, represent a pool of overhead for all the years of practice; b) the laterality / rotational direction, because most gymnasts use more one side, which consequently suffer more impacts.

3.5.1. Gender, Chronological age and maturation

Age and gender data related to UV in immature and mature reference samples, is given in Table 4.
Theoretical Background

Ulnar variance in gymnasts

Table 4 - Age and gender related ulnar variance data (UV, in mm) in immature and mature reference samples: an overview

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample studied</th>
<th>Description sample</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>age (y)¹</td>
<td>n</td>
<td>age (y)</td>
</tr>
<tr>
<td>Nakamura et al.</td>
<td>325 14-79</td>
<td>203 ?</td>
<td>122 ?</td>
</tr>
<tr>
<td>(1991)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schuind et al;</td>
<td>120 25-60</td>
<td>30 25-40</td>
<td>30 25-40</td>
</tr>
<tr>
<td>(1992)</td>
<td></td>
<td>30 41-60</td>
<td>30 41-60</td>
</tr>
<tr>
<td>Freedman et al.</td>
<td>100 19-61</td>
<td>42 ?</td>
<td>58 ?</td>
</tr>
<tr>
<td>(1998)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jung et al.</td>
<td>120 20-35</td>
<td>60 ?</td>
<td>60 ?</td>
</tr>
<tr>
<td>(2001)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yoshioka et al.</td>
<td>29 14-67</td>
<td>? ?</td>
<td>? ?</td>
</tr>
<tr>
<td>(2007)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen and Wang</td>
<td>864² 23-69</td>
<td>471 2008</td>
<td>393 2008</td>
</tr>
<tr>
<td>(2008)</td>
<td>864² 42-81</td>
<td>471</td>
<td>393</td>
</tr>
</tbody>
</table>

(to be continued)
### Table 4 – continued

<table>
<thead>
<tr>
<th>Study</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Gender</th>
<th>Age 1</th>
<th>Age 2</th>
<th>Reference (USA)</th>
<th>UV measures (PRPR and DIDI)³ change</th>
<th>Age Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hafner et al. (1989)</td>
<td>535</td>
<td>2-15</td>
<td></td>
<td>276</td>
<td>2-15</td>
<td>Cross-sectional</td>
<td>Very little with age, but the ranges of both measures increased significantly with age.</td>
<td>Initial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range PRPR at 2: -0.3 / -3.8</td>
<td>Final</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range PRPR at 15: +2.4 / -7.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range DIDI at 2: -0.7 / -4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range DIDI at 15: +1.8 / -7.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gender was not significant.</td>
<td></td>
</tr>
</tbody>
</table>

1 Age is given in range and expressed in years
2 Longitudinally followed over a period between 17 and 22 years. Start of the study is indicated as initial stage and the end of the study is indicated as final stage.
3 PRPR refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / DIDI refers to the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis.
It is expected that gender and age could influence wrist bone morphology. Several authors failed to find a significant relationship between UV measurements and gender in immature and mature reference populations (Freedman et al., 1998; Hafner et al., 1989; Schuind et al., 1992), even when comparing the two extremes of their range: -3.8 to +2.3 mm in males and -4.2 to 1.6 mm in females (Schuind et al., 1992). Also in more recent studies (Chen & Wang, 2008; Yoshioka et al., 2007) no significant differences in UV according to gender was observed.

However, in contrast to these results, Jung et al. (2001) reported that UV was significantly different when related to gender in a mature population; females exhibited a more positive UV than males (ranging from -2.28 to +4.68 mm and from -2.08 to +3.64 mm, respectively). Similar results were found by other authors (Nakamura, Tanaka, Imaeda & Miura, 1991) with UV ranging from -0.14 mm for males to +0.77 mm for females.

It was observed that all reported data concerning the relationship between UV and both gender and age within the general population are from studies carried out on American and Asiatic samples. Studies on European samples could not be found. Therefore, ethnographic-related factors can possibly explain some UV differences (Jung et al., 2001; Schuind et al., 1992; Yoshioka et al., 2007).

Concerning the relationship between UV and age, in our opinion it is important to analyze the relationship between UV and the gymnast’s maturational status instead of chronological age, in order to define the type of association between UV and skeletal age. In this context, it is important to analyze separately the studies where UV is related to chronological age, in contrast to studies where UV is related to skeletal age, in both mature and immature subjects, in the general population and gymnast’s samples.

We would like to point out that the evaluation of UV behavior with increasing age (both chronological and skeletal) and the observation of possible changes in a specific age group, would eventually enable the creation of normative values that would allow to predict the cause-effect from extrinsic factors, such as the effect of training in gymnastics.
3.5.1.1. Studies relating UV and chronological age - gymnasts

Many authors (Beunen et al., 1999; Claessens et al., 1996; De Smet et al., 1994; DiFiori et al., 2002a; DiFiori et al., 1997) couldn’t find a relationship between chronological age and UV in immature gymnasts. In contrast, Dwek et al. (2009) observed a significant trend from a negative towards a more positive UV with advancing age. On the other hand, Claessens et al. (1997) find negative UV values which became more pronounced with advancing age in a longitudinal study performed on female gymnasts.

3.5.1.2. Studies relating UV and skeletal age - gymnasts

Through the study of skeletal maturation in each bone, Beunen et al. (1999) postulated a non-association between positive UV and advanced maturity status of the radius or the advanced fusion of the epiphyseal-diaphyseal junction. Claessens et al. (2003) didn’t find a significant relation between UV and skeletal age. Meanwhile, a significant positive association between UV and skeletal maturity was reported by Amaral et al. (2012a) \( r = 0.38; p \leq 0.05 \) for DIDI) and by Claessens et al. (1996) \( r = 0.16 \) for DIDI; \( r = 0.22 \) for PRPR), with the latter considering that mature female gymnasts have a greater risk of developing positive UV. However, the correlations between somatic and maturational characteristics with UV were rather low and almost the same for both variance measures (PRPR and DIDI).

3.5.1.3. Studies on general populations

In mature populations, some authors have reported no significant UV change with increasing chronological age (Chen & Wang, 2008; Freedman et al., 1998; Schuind et al., 1992; Yoshioka et al., 2007). On the other hand, for immature subjects, Hafner et al. (1989) observed that the ranges of both UV measures increase significantly with age.

Therefore, there is a need to standardize UV values in chronological and skeletal age categories in the immature general population in order to be able to observe the normal evolution of the ulna/radio lengths, excluding the effect of weight-bearing in this joint. This is the best way to find out if, in fact, gymnastics
skills can cause load injuries and subsequent arrest of radial growth plates, leading to a positive UV.

The relationship between ulnar variance and biological parameters in gymnastics samples can be observed in Table 5.
Table 5 - Relationship between ulnar variance and biological parameters in gymnastics samples: an overview

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample studied</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Gender</td>
</tr>
<tr>
<td><strong>Immature gymnasts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Smet et al. (1994)</td>
<td>156</td>
<td>F</td>
</tr>
<tr>
<td>Claessens et al. (1996)</td>
<td>156</td>
<td>F</td>
</tr>
<tr>
<td>Claesens et al. (1997)</td>
<td>36</td>
<td>F</td>
</tr>
<tr>
<td>DiFiori et al. (1997)</td>
<td>44</td>
<td>M+F</td>
</tr>
<tr>
<td>Beunen et al. (1999)</td>
<td>201</td>
<td>F</td>
</tr>
</tbody>
</table>

(to be continued)
### Theoretical Background

**Ulnar variance in gymnasts**

#### Table 5 - continued

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Gender</th>
<th>Age Range</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiFiori et al. (2002)</td>
<td>59</td>
<td>M+F</td>
<td>5 - 16</td>
<td>UV was not significantly related with chronological age.</td>
</tr>
<tr>
<td>Claessens et al. (2003)</td>
<td>16</td>
<td>F</td>
<td>6 - 13</td>
<td>UV is not related with height, weight and skeletal age.</td>
</tr>
<tr>
<td>Dwek et al. (2009)</td>
<td>10</td>
<td>F</td>
<td>12 - 16</td>
<td>With increasing age was observed more positive UV.</td>
</tr>
<tr>
<td>Amaral et al. (2012a)</td>
<td>33</td>
<td>F</td>
<td>7.2 - 15.4</td>
<td>UV is significantly (p &lt; 0.05) associated with skeletal age (r = 0.38), stature (r = 0.41), and fat-free mass (r = 0.48)</td>
</tr>
</tbody>
</table>
3.5.2. Anthropometric characteristics

No significant relationships between UV and normative somatic parameters, such as height and weight, have been observed. This lack of relationship can possibly be explained by the fact that in the normal population, the upper limbs were not used in ‘normal’ daily activities similar to gymnastics, therefore, do not present significant values of UV modifications.

Unlike most other sports, gymnasts require the use of the wrists as weight-bearing joints, receiving impact loads. Supposedly, heavier gymnasts are more likely to be injured due to the high forces absorbed by the musculoskeletal system (Emery, 2003), so gymnasts with excessive body weight may present greater risk of overload and overuse injuries.

De Smet et al. (1994), Claessens et al. (2003) and Amaral et al. (2012a) have all observed significant positive associations between UV and both height and weight in female gymnasts, despite the fact that DiFiori et al. (1997) couldn’t find a relationship between these variables.

Other variables of body composition are likely to influence the UV in gymnasts, such as percentage of body fat, fat-free mass and muscular mass. There are potential alterations in the distal physis of the radius in low level gymnasts, especially those who have high percentage of body fat, which may present a more pronounced UV (Caine et al., 1992; O’Connor et al., 1996). According to Claessens et al. (1996), high level gymnasts (participants in the world-championships), who are taller, heavier and with a higher muscular mass, tend to present more positive UV. These authors defend the concept that gymnasts who have higher mechanical load on the wrists, have a greater predisposition to develop positive UV, although only few studies support these assumption.

Concerning fat-free mass, Amaral et al. (2012a) observed a rather low, but significant correlation ($r = 0.48$) with DIDI, while Claessens et al. (1996) found no significant association between UV and variables related with fat development.
Nevertheless, it cannot be concluded per se that weight and/or height or even other somatic components may contribute to changes in UV, regardless of training and genetic characteristics. It is necessary to know the UV from each gymnast at the beginning of his sport activity and throughout his career, analyzing UV both independently and simultaneously in relation with other variables.

3.5.3. Dominance / Laterality

According to several authors, the positive UV observed in gymnasts is a consequence of the excessive physical loading on the wrist, being predictable that the dominant hand presents higher positive UV, because it suffers heavier load (Claessens et al., 1998).

However, the concept of dominance and laterality is not unanimous. In the study of Claessens et al. (1998) on 36 female gymnasts of the Flemish region of Belgium, aged 8 - 14 years, dominance was determined by the rotational direction considering the first hand of support when performing a cartwheel. No significant differences were observed in UV between the dominant (mean PRPR = -1.3 mm) and non-dominant wrists (mean PRPR = -1.2 mm) measured by the method of Hafner et al. (1989), suggesting an absence of relationship between the rotational direction and UV. However, one has to take into consideration the fact that gymnasts, when performing a cartwheel to a particular side, do not necessarily perform all other support rotational movements in the same direction. For this reason, it is difficult to state that the load supported in either left or right wrists is the cause of a modification in UV, without first accurately quantifying all wrist weight-bearing results from training.

Regarding laterality, Claessens et al. (1998) found a small but significant difference between the UV results of the right (mean PRPR = -1.6 mm) and the left (mean PRPR = -0.8 mm) wrist for PRPR, in 36 female immature gymnasts. DiFiori et al. (2002a) did not observe a significant association between hand dominance and UV in a group of 59 male and female nonelite gymnasts from United States of American (USA). A mean side-to-side difference in UV of 0.7 ± 0.6 mm was found that was not associated with hand dominance of the gymnasts as gathered by a questionnaire. In a group of 33 nonelite Portuguese
female gymnasts, Amaral et al. (2012a) found a significant difference between left and right wrists for the PRPR variable (PRPR-L = -1.7 mm / PRPR-R = -2.2 mm), in contrast to a non-significant difference when DIDI was taken as the UV measure, -2.8 mm and -3.1 mm for the left and right wrists respectively. In an adult reference sample (n = 100), Freedman et al. (1998) did not find a significant difference between right and left determined ulnar variance, with mean values of -0.13 mm and -0.29 mm for the left and right sides respectively. However, notable individual variations were observed. An overview of right versus left ulnar variance results is given in Table 6.
### Theoretical Background

#### Ulnar variance in gymnasts

Table 6- Overview of left-right difference of ulnar variance (PRPR) measurements

<table>
<thead>
<tr>
<th>Reference</th>
<th>Population</th>
<th>Method</th>
<th>Left site (mm)</th>
<th>Right site (mm)</th>
<th>Difference (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiFiori et al. (1997)</td>
<td>2 ≤ 6 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-1.0</td>
<td>-1.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>30 7-13 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-2.0</td>
<td>-2.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>12 14-15 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-1.6</td>
<td>-1.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Claessens et al. (1998)</td>
<td>36 8-14 / F nonelite gymnasts</td>
<td>PRPR, DIDI</td>
<td>-0.8, -4.9</td>
<td>-1.6, -4.8</td>
<td>0.8*, 0.1</td>
</tr>
<tr>
<td>Freedman et al. (1998)</td>
<td>100 19-61 / M+F adult reference data</td>
<td>Perpendicular</td>
<td>-0.13</td>
<td>-0.29</td>
<td>0.16</td>
</tr>
<tr>
<td>DiFiori et al. (2002)</td>
<td>59 5-16 / M+F nonelite gymnasts</td>
<td>PRPR, DIDI</td>
<td>?</td>
<td>?</td>
<td>0.7</td>
</tr>
<tr>
<td>Amaral et al. (2012a)</td>
<td>33 7-15 / F nonelite gymnasts</td>
<td>PRPR, DIDI</td>
<td>-1.7, -2.8</td>
<td>-2.2, -3.1</td>
<td>0.5*, 0.3</td>
</tr>
</tbody>
</table>

*PRPR and DIDI refers to the method of Hafner et al. (1989) / PRPR refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / DIDI refers to the measurement obtained using the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis / Perpendicular refers to the method described by Steyers and Blair (1989). * p ≤ 0.05
3.5.4. Handgrip strength

Ulnar variance is affected by handgrip strength (Sönmez et al., 2002). UV increases significantly with a strong handgrip motion and returns to its original status with cessation of the motion (Cerezal et al., 2002), illustrating the dynamic character of UV (Schuurman et al., 2001). During the handgrip strength motion the radio-ulnar glide is greater for wrists with negative UV (Sönmez et al., 2002) and UV within individuals is not uniformly symmetrical (Freedman et al., 1998).

The magnitude of UV varies considerably with handgrip motion, generally with an amplitude between 1 and 2 mm (Cerezal et al., 2002; Tomaino, 2000), and it has been shown that the small changes in ulnar variance have a direct relationship with the magnitude of load-bearing (Sönmez et al., 2002). Changes in ulnar variance under 1 mm can alter mechanical transfer load characteristics by more than 25% and probably have particular clinical significance in individuals who perform repetitive rotational manoeuvres with load on the wrist, as in sports like gymnastics (Mann et al., 1992; Yoshioka et al., 2007).

In fact, a strong handgrip in pronation results in a significant proximal migration of the radius leading to an increase in UV (Cerezal et al., 2002; Schuurman et al., 2001; Sönmez et al., 2002).

Performing exercises on high bar, parallel bars, pommel horse and rings, where gymnasts use this kind of grip, increases the probability of ulnar impact. Therefore, if immature gymnasts are predisposed to have a negative UV, and since UV increases significantly with a strong handgrip and pronation, both factors may increase the glide of proximal radius, making the UV more neutral or even positive, decreasing the forces on the radial growth plates and therefore may be beneficial to support the load characteristics of gymnasts training.

Studies about gymnasts involving the relationship between UV and handgrip strength are scarce. In a group of 59 nonelite male and female gymnasts, aged 5 - 16 years, DiFiori et al. (2002a) did not find significant relationship between UV and handgrip strength.

A summary of studies in which the relationship between UV and handgrip strength was investigated is given in Table 7.
**Theoretical Background**

**Ulnar variance in gymnasts**

Table 7 - Relationship between UV and handgrip strength: an overview

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample size</th>
<th>Gender</th>
<th>Sample characteristics</th>
<th>Results</th>
<th>Relation with hand grip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td>Mean UV (mm)</td>
<td></td>
</tr>
<tr>
<td><strong>Immature wrists</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DiFiori et al. (2002a)</td>
<td>59</td>
<td>M+F</td>
<td>Nonelite gymnasts (USA)</td>
<td>-1.7</td>
<td>No association</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mature wrists</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freedman et al. (1998)</td>
<td>100</td>
<td>M+F</td>
<td>Adult reference sample</td>
<td>Unloaded Left = -0.13</td>
<td>Not significant differences on average of UV measurements between right and left unloaded or loaded wrists.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right = -0.29 Loaded Left = +0.93</td>
<td>Significant individual variations between unloaded and loaded wrists.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right = +0.82</td>
<td></td>
</tr>
<tr>
<td>Schuurman et al. (2001)</td>
<td>68</td>
<td>M+F</td>
<td>Patients (The Netherlands)</td>
<td>Unloaded Left = +0.22</td>
<td>With maximum strength (loaded) a significant increase towards positive UV is observed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right = +0.10 Loaded Left = +2.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right = +2.18</td>
<td></td>
</tr>
<tr>
<td>Sönmez et al. (2002)</td>
<td>41</td>
<td>M</td>
<td>Volunteer sample (Turkey)</td>
<td>Unloaded +0.06 Loaded +1.87</td>
<td>The difference in UV between unloaded and loaded was significant. UV increase with increase in grip strength. UV during grip strength was increased in wrists with negative UV and greater than those with positive UV.</td>
</tr>
</tbody>
</table>


3.5.5. Hyper-mobility / Range of motion

Boyle, Witt & Riegger-Krugh (2003) have reported generalized joint laxity as a potential risk factor for a variety of injuries and musculoskeletal complaints. Unver et al. (2004) stated that there are few studies about the association between UV and range of motion.

Significant differences were found between UV and different wrist positions (Schuurman et al., 2001) supporting the influence of forearm rotation on UV measures (Jung et al., 2001; Sönmez et al., 2002). Pronation causes an increase of ulna length concerning the distal end of the radius, and supination favours the decrease in the ulna length (Anderson et al., 1998; Cerezal et al., 2002; De Smet, 1994; Sönmez et al., 2002).

To our knowledge, most of the studies investigating the relationship between UV and mobility of the wrists were done in non-athletic, normal samples (Table 8).
## Theoretical Background

### Ulnar variance in gymnasts

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample Characteristics</th>
<th>Results</th>
<th>Relation with forearm / wrists position</th>
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<tbody>
<tr>
<td><strong>Mature wrists</strong></td>
<td></td>
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<tr>
<td>Schuurman et al. (2001)</td>
<td>Patients (Netherlands)</td>
<td>Neutral = +0.16</td>
<td>Significant differences were found between UV and different wrist positions.</td>
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<tr>
<td></td>
<td></td>
<td>Left = +0.22</td>
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<td></td>
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<td>Right = +0.10</td>
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<tr>
<td></td>
<td></td>
<td>Supination = -0.26</td>
<td>Neutral / supination: significant (p &lt; 0.01).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left = -0.22</td>
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<td></td>
<td></td>
<td>Right = -0.29</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ulnar deviation = +0.30</td>
<td>Ulnar / radial deviation: Not significant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial deviation = +0.32</td>
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</tr>
<tr>
<td>Yeh et al. (2001)</td>
<td>Volunteer sample (USA)</td>
<td>Neutral = -0.8</td>
<td>UV decreased with the forearm rotation from pronation to supination.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pronation = -0.4</td>
<td>Pronation / neutral: significant (p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supination = -1.0</td>
<td>Pronation / supination: significant (p &lt; 0.01)</td>
</tr>
<tr>
<td>Jung et al. (2001)</td>
<td>Volunteer sample (Korea)</td>
<td>Neutral = +0.74</td>
<td>Forearm rotation can influence UV.</td>
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<tr>
<td></td>
<td></td>
<td>Pronation = +1.07</td>
<td>UV tended to increase with pronation and decrease with supination.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supination = +0.19</td>
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</tr>
<tr>
<td>Sönmez et al. (2002)</td>
<td>Volunteer sample (Turkey)</td>
<td>Neutral = +0.06</td>
<td>UV is affected by forearm rotations.</td>
</tr>
<tr>
<td>Unver et al. (2004)</td>
<td>Medical students and nurses (Turkey)</td>
<td>Neutral = +0.06</td>
<td>Ulnar deviation was greater in negative UV: significant (p &lt; 0.02).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial deviation was greater in neutral UV: significant (p &lt; 0.035).</td>
<td>In the total range of radio-ulnar deviation in neutral or negative UV: not significant.</td>
</tr>
</tbody>
</table>
In a gymnastics population, this association was partly investigated in a small group (n = 16) of 16-year-old sub-elite female Flemish gymnasts (Claessens, 2004; Vandenbussche, 2002). Significant correlations between UV and some mobility measures were found: hyper-extension of the fingers \((r = +0.65)\) and hyper-extension of the elbow \((r = +0.52)\). The results of this preliminary study suggest that more flexible gymnasts are at a greater risk for developing positive UV.

### 3.5.6. Pain

Some authors support the theory that pain represents the first stage of an overuse injury which progressively causes a stress injury in the distal extremity of the radius (growth inhibition), allowing the development of positive UV (DiFiori et al., 2002a; DiFiori, Puffer, Aish & Dorey, 2002b). Others believe that painful wrist syndrome is frequently the result of the ulna’s overgrowth (positive UV), caused by biomechanical forces that are inherent to gymnastics activities, affecting negatively the radius distal growth plate (Caine et al., 1992; Roy et al., 1985).

The UV and wrist pain in gymnasts increase proportionally with age and total weekly training hours, but this falls short of a cause-effect relationship (Claessens, 2004; DiFiori et al., 2002a). Although several authors (DiFiori et al., 1997) have not observed substantial association between UV and wrist pain, gymnasts with wrist pain presented more negative ulnar variance than those without wrist pain (DiFiori et al., 2002a).

Hypothetically, the gymnasts with the highest absolute values of negative UV are expected to present more pain and radiologic changes in the radial growth plate, and consequently pain on the radial side, as well as during the execution of supination and ulnar deviation. These movements increase distal radial slide, accentuating the negative UV and increasing the percentage of load on the radius. Oppositely, for individuals with positive UV, the distal ulnar and its interface with the carpal bones may have a greater probability of suffering damage or injuries.
3.5.7. Training characteristics

During the last decade a significant increase in the duration, the volume and intensity of AG training is observed as shown in several studies (Caine, Bass & Daly, 2003), with reports from elite gymnasts who train about 40 h/week, 5-6 days/week, throughout the year (Caine, Lewis, O'Connor, Howe & Bass, 2001; Daly et al., 2001; Dixon & Fricker, 1993; Kirialanis et al., 2002). According to some authors (Gabel, 1998; Kolt & Kirkby, 1999), the percentage of injuries is proportional to the amount of training time and the skill level due to the increase of time exposed to increased difficulty in competition routines.

The injury profile depends on the amount of time spend in the sports environment (Gabel, 1998) and as demonstrated in several studies, the excessive stress on the skeleton of elite gymnasts is caused by the number of repetitions of a specific movement (DiFiori et al., 2006; Roy et al., 1985). In most studies, especially case-reports, the authors suggest a dose-response relationship between training characteristics, competition level and UV (Claessens, 2001; 2004). Thus, the higher the gymnasts’ training and/or competition level, the more pronounced positive ulnar variance is observed (Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2002a; Roy et al., 1985). However, there does not appear to be a consensus on this matter. In a study on a representative sample of 156 skeletally immature elite female gymnasts (participants in world championships), Claessens et al. (1996) did not find any significant correlation between training status and competition scores on the one hand, and UV on the other hand, correlation values varied from $r = -0.11$ ($r$ between starting age and UV) and $r = +0.15$ ($r$ between competition score on uneven bars and ulnar variance). DiFiori et al. (1997) also did not find a significant association between ulnar variance and training history in 44 nonelite male and female gymnasts. Based on data gathered on 36 female gymnasts who were followed longitudinally for four years, Claessens et al. (1997) could not show a significant influence of gymnastics training load and the ulnar variance phenomenon. On the other hand, DiFiori et al. (2002a) found a significantly higher positive UV in a group of elite collegiate gymnasts compared to a group of nonelite collegiate gymnasts. According to Beunen et al. (1999), studying the association between skeletally assessed maturation and
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gymnastics training in a group of highly-skilled world-level female gymnasts, was frequently found positive UV in gymnasts that may not have resulted from gymnastics overload. Also, based on data gathered on 36 skeletally immature female gymnasts in which UV was measured annually over 7 or 8 years, Claessens et al. (2003) have shown that the observed negative UV at the start of the study became more pronounced over the years when training level increased, contradicting the results of positive UV found in the literature. For this reason, some authors consider that AG training does not have a direct negative impact in the relative position of the distal extremities of the ulna compared to the radius, resulting in an ulna’s overgrowth. Other studies have also pointed out that there is no significant relationship between UV and intensity or volume of gymnastics training (Claessens, 2001; 2004; De Smet, 1994; DiFiori et al., 1997).

Although several authors indicate that injuries may be related to the difficulty of sports skills and the athlete’s capability (Kolt & Kirkby, 1999; Sands, Shultz & Newman, 1993), several studies didn’t find any significant association between training or competition level and UV, neither in high level athletes nor recreational groups (Claessens et al., 1996; Claessens et al., 1997; De Smet, 1994). In contrast, DiFiori et al. (2002a) have found associations between UV, higher skill level, and years of training.

The stress changes in the growth plate and the long-term consequence in the chronically stressed wrists of adolescent gymnasts was also observed by Chang et al. (1995) over many years of training. They found that the tendency toward positive UV ranged from 23.6% in the 1st year of training to 81% in the 8th year of training (Chang et al., 1995). In contrast, Claessens et al. (1997) found a tendency toward negative UV varying between -3.4 and -6.5 mm for DIDI.

4. LIMITATIONS

The research on this matter often presents contradictory results, which can be caused by the disparity of sample characteristics, lack of criteria concerning the training level, number of subjects studied, or even the different evaluation
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techniques used and their reliability, resulting in a lack of consensus concerning the type of UV in gymnasts. Because most studies are cross-sectional designs, there are many controversial results which do not allow the determination of precise relationships. Longitudinal studies are needed in order to study more effectively the amount of response or influence of training in the UV phenomenon.

There is a lack of information about UV normative values related to age, gender and ethnic groups which would make it easier to detect and distinguished the abnormalities in athletes submitted to a weight bearing on the wrists. It is also important to point out that the majority of recent researches involving UV investigate this phenomenon in patients with already established diseases and therefore without assessing its etiology or evolution.

5. PRACTICAL APPLICATIONS OR PREVENTIVE MEASURES

Based on the presented information related to the UV and respective causes or consequences, prevention should be an important aspect of a gymnast’s training regimen (Webb & Rettig, 2008). In this context, a periodic physical examination should be carried out to allow an accurately diagnosis at an early stage of the stress related to growth plate and other overuse wrist injuries. When indicated, radiographs of symptomatic physeal areas should be administered to rule out stress changes (Caine, 2003; Caine et al., 2006; Kolt & Kirkby, 1999).

Due to the frequency and high level of impacts that gymnasts suffer during AG practice, coaches should reduce training loads and delay some skill progressions for young gymnasts during growth spurts (Caine, 2003; Caine et al., 1996; Caine et al., 1992; DiFiori et al., 2006; Webb & Rettig, 2008). In order to easily identify the referred period of rapid growth they should have a control of the height measurements at three month intervals or quarterly height measurements (Caine, 2003; Caine et al., 2006; DiFiori et al., 2006).

Coaches should also use a variety of drills or activities during the training to avoid excessively repetitive movements that may result in overuse injury. Emphasis should be on quality of workouts rather than training volume (Caine
et al., 2006) and the training load should be gradually increased (Daly et al.,
2001; Webb & Rettig, 2008). Another possibility to lighten the load can be the
alternation of loading types during workouts (DiFiori et al., 2006; Webb & Rettig,
2008), alternating between movements of swing and support to reduce stress
and the intensity of compressive loading on the wrist (Caine, 2003; DiFiori et al.,
2006; Mitchell & Adams, 1994; Roy et al., 1985).

It is also important to consider the possibility of use wrists orthoses (Webb &
Rettig, 2008). Nowadays many gymnasts use various types of wrist braces and
biomechanical and clinical studies indicate that such devices may protect
against acute injury and may reduce ulnocarpal joint pressure during loading
(DiFiori et al., 2006; Grant-Ford, Sitler, Kozin, Barbe & Barr, 2003), mainly the
skeletally mature gymnasts with a positive UV. Brooks, (2001) have reported a
case where the use of wrist brace, combined with palmar wrist tape, proved
effective in preventing end-range of the wrist extension while still allowing the
athlete adequate mobility to successfully perform the skills. However, the
biomechanical studies of wrist bracing have not been performed in specimens
with a negative UV, so the potential effects of using such braces in young
gymnasts, who typically have a negative UV, are not known (DiFiori et al.,
2006).

The use of devices with bearing surfaces adapted to reduce the pressure of the
impacts can be a useful strategy, especially during the sensitive phases of rapid
growth. Foam beam covers and padded vault should be used to absorb the
shock of impact (Daly et al., 2001; Mandelbaum et al., 1989; Mitchell & Adams,
1994).

Finally, because UV and related factors cannot be dissociated from the
maturation status of the gymnasts, training and skill development should be
individualized (Caine, 2003; DiFiori et al., 2006) to reduce risk of acute and
stress related physeal injury (Caine et al., 2006). To ensure that the specific
physical characteristics and maturation are considered throughout the training
process it is important that everyone involved work as a team (gymnast, coach,
physician, parents and medical staff) with open channels of communication
(Caine et al., 2006).
6. CONCLUSIONS

The gymnast's wrist is a place of great incidence of painful symptomatology and injury, leading to the formulation of several hypotheses concerning the UV ethiology. Based on the previous assumption, it seems relevant to determine the circumstances in which gymnasts have an increased risk of developing changes in reference values of UV and which are the causes of pain and functional disability, in order to reduce the occurrence, recurrence and severity of injuries. In this context, it is important to carry out longitudinal studies, which take into account the gymnasts' pre- or post-pubescent stages, controlling as much as possible for confounding variables. Most of the available studies are based on patients or case reports. In fact, in case-study or in cross-sectional research, the temporal association between exposure and outcome is unclear. In many similar studies or nonrandomized interventions, various sources of bias were detected namely the selection of subjects, methodological concerns, measurement of exposure and outcome variables, and lack of control concerning other potentially confounding variables which may threaten the studies' internal validity. Future clinical trials looking for prevention strategies should quantify and control the potential risk factors for injury in young gymnasts, including changes in the physis growth plate from distal radius and/or ulna. It is important to diagnose quickly and accurately the specific injury to adapt training and to appropriately initiate the treatment and limit the extent of injuries. Prevention should also be an important aspect of a gymnast's training regimen during all activity.
Study I

*Experimental article*

**Ulnar variance related to biological and training characteristics and handgrip strength in Portuguese skeletally immature female gymnasts**

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**Running head:** Ulnar variance related to biological and training characteristics and handgrip strength

**Keywords:** Gymnasts; Ulnar variance; Training; Muscle strength

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Abstract

Aims: The aims of this study were to investigate the ulnar variance in a group of skeletally immature female gymnasts of different age and skill level and to investigate the left-right differences in ulnar variance and its relationship with biological and training characteristics and handgrip strength.

Methods: Thirty-three Portuguese skeletally immature female gymnasts (mean age 11.1 years) of different age-related categories completed a questionnaire detailing their training characteristics. Besides maturation, stature, body mass, and body composition, also handgrip strength of both hands were measured. Left and right ulnar variance was obtained using the Hafner’s procedure and skeletal age through the Tanner-Whitehouse 3-method.

Results: Mean skeletal age (10.1 ± 1.9yr) is one year younger than chronological age (11.1 ± 2.1yr) and this discrepancy becomes more pronounced with increasing age-category.

Gymnasts presented on average 6.1 years of training and 16.7 hours/week. A negative mean value for both the left and right ulnar variance measures was observed (between -1.7mm and -3.1mm) but with increasing age-category there is a trend that ulnar variance becomes more positive (between +0.3mm and -1.0mm). Significant differences between right and left ulnar variance were demonstrated. Correlations between ulnar variance and biological and training characteristics, and handgrip strength are rather low and not significant, except for skeletal age (r=0.38), stature (r=0.41) and fat-free mass (r=0.48).

Conclusions: Despite some significant results the main results of this study do not directly support the thesis that gymnastics training or handgrip strength are associated with ulnar variance.
1. Introduction

There seem to be an increasing number of children who specialize in a sport at an early age, train year-round for a sport, and/or compete on an elite level (Pediatrics, 2000). This is especially the case in "women's" artistic gymnastics. The significant growth and popularity of women's gymnastics became more and more evident after the 1972 and 1976 Olympics, where stars as Olga Korbut and Nadia Comaneci introduced the world, via the media, to this artistic sport (Ryan, 1995). The increasingly dominant performance of younger, smaller-sized gymnasts accompanied this popularity (Claessens, 2009; Webb & Rettig, 2008). The majority of elite female gymnasts also tend to be later-maturing individuals (Claessens, 2009; Thomis et al., 2005). In general, present-day elite women's artistic gymnastics has evolved to favor the body of a child in contrast to that of a maturing adolescent or young adult (Claessens, 2009; Claessens et al., 1991; Daly et al., 2001). On the other hand, the difficulty of maneuvers practiced and performed has increased. Frequency, duration, and intensity of training have also increased (Sands, 2000). Female gymnasts range from the very young child involved in tumbling exercises to the outstanding gymnast training intensively for competitions such as the World Championships and/or the Olympics (Daly et al., 2001; Webb & Rettig, 2008). Elite female gymnasts may initiate training as early as 4 or 5 years of age and quickly accelerate the difficulty and intensity of their training (Daly et al., 2001; Webb & Rettig, 2008). On average, outstanding female gymnasts trains 5 to 6 days per week and 5 hours a day, and may peak 50 hours each week (Claessens et al., 1996; Daly et al., 2001; Webb & Rettig, 2008). On average, these gymnasts may exercise 700 to 1300 elements per day, which correspond to an amount of 220,000 to 400,000 elements per year (Sands, 2000). Increased involvement and difficulty of gymnastic skills practiced at an early age and continued through the years of growth raises concern about risk and severity on injury, more specifically overuse injuries, to these young children (Caine et al., 2006; Caine et al., 1996; Daly et al., 2001; Micheli et al. 2008). Unlike most other sports, gymnastics requires use of the upper extremities as weight-bearing limbs, causing high-impact loads to be distributed through the elbows and the wrist. It is demonstrated that the wrist is subjected to forces that can exceed twice body
weight, and rates of loading up to 16 times body weight have been reported (Burt, Naughton, Higman & Landeo, 2010). Given the high impact loads, upper extremities are the second most frequently injured body region and the wrist is the most frequently injured site in the upper extremity of female gymnasts followed by the elbow, as demonstrated by several overview studies (Caine et al., 2006; Webb & Rettig 2008). In a recent paper about the injury profile in women’s gymnastics, 79 Portuguese female gymnasts (6 to 18 yr) were studied during an entire season, and the wrist was the fourth most frequent injury and had the highest incidence (8.7%) in the upper limb (24.4% of total injuries) (Amaral, Santos & Ferreirinha, 2009).

In the literature, a lot of attention is given to the wrist problems in gymnasts, with special emphasis on the problem of wrist pain (DiFiori, 2006; DiFiori et al., 2006; Dwek et al., 2009; Webb & Rettig, 2008). Among others, wrist pain in gymnasts is often viewed as a result of epiphysial trauma and related changes caused by repetitive gymnastic loading mainly of the distal end of the radius as its interface with the carpals (Caine et al., 2006; DiFiori et al., 2006). Also, a significant amount of research has been carried out to investigate the relationship between distal radial stress injuries and ulnar variance (UV) (Webb & Rettig, 2008). UV refers to the relative positioning of the distal end of the ulna relative to the distal end of the radius. It is often claimed that repetitive injury to the radial epiphysis in the skeletally immature growing gymnast may inhibit normal growth of the radius resulting in a positive UV, i.e., ulnar overgrowth (Caine et al., 2006; Caine et al., 1996; Chang et al., 1995; De Smet et al., 1994; DiFiori et al., 2006; DiFiori et al., 1997; Mandelbaum et al., 1989). Alternatively, it has been suggested that the positive UV is an individual characteristic, in part genetically influenced (Beunen et al., 1999; DiFiori et al., 2006).

The UV type may predispose gymnasts to specified injuries and/or symptomatologies (Amaral, Claessens, Ferreirinha & Santos, 2011). Several pathological conditions are correlated with negative UV, namely the carpal instability, ulnar subluxation of the carpals, avascular necrosis of the scaphoid and scapholunate dissociation (De Smet, 1994). Nishiwaki et al. (2005) have reinforced the possibility that higher values of negative UV are associated with
increased pressure over the distal radio-ulnar joint and a greater probability of degenerative alterations. In this context, it seems reasonable that wrists with high levels of negative UV may present a higher prevalence of pain and abnormal radiographic signs in the distal radial growth plate (DiFiori et al., 2002a). On the other hand, the positive UV in gymnasts may increase the ulnar carpal loading (Palmer et al., 1982) or contribute to the ulnar impact syndrome, degenerative injuries, cartilaginous wear of carpal bones, rupture of the triangular fibrocartilage complex and osteomalacia of the ulnar carpals (De Smet, 1994).

Although rather limited studied, it is also demonstrated that positive UV may be more frequent in gymnasts who are older, heavier, taller and better muscularily (higher fat-free mass) built (Claessens et al., 1996; DiFiori et al., 2006). As stressed by several authors, among others physical conditioning, strengthening of the muscles around the wrist is important as a countermeasure in both the prevention and rehabilitation of wrist injuries (Daly et al., 2001; Webb & Rettig, 2008). To our knowledge, however, little is known about the relationship between wrist injuries, and more specifically UV, and arm muscle strength. From a methodological point of view, UV can also vary from side to side in an individual, resulting in significant right-left differences (Claessens et al., 1998; DiFiori, 2006; Freedman et al., 1998), with the consequence that studies in gymnasts in which UV is measured by randomly selecting a single wrist may underestimate UV (DiFiori, 2006). Studies in which the relationship between UV, as measured on both sides, and biological and training characteristics of gymnasts are, however, scarce and further investigation is needed.

The aims of this study are: a) to investigate the UV in a group of Portuguese skeletally immature female gymnasts of different age-category; b) to investigate the left-right differences in UV and its relationship with biological and training characteristics and handgrip strength in this group of gymnasts.
2. Methods

2.1 Subjects

The sample consisted of 33 Portuguese skeletally immature female artistic gymnasts. Their chronological age varied from 7.2 yr until 15.4 yr with a mean age of 11.1 ± 2.1 yr. All gymnasts were in the premenstrual period, except one gymnast from group C who had her menarche when she was 15.

All gymnasts compete at national and/or international level and were recruited from several clubs of different cities from Portugal around Porto and Lisbon.

The total group was divided into three subgroups according to the competition levels defined by the Portuguese Federation of Gymnastics (FGP) which is in accordance to the “Age Group Development Program” (AGDP) from the International Gymnastics Federation (F.I.G., 1997).

Group A comprised gymnasts who compete exclusively with compulsory exercises from FGP and correspond to the “Beginners and Advanced” groups from AGDP (F.I.G., 1997) which include the skill level of initiation, preparation and basic technical skills acquisition, aged 6-9 yr (n=7); a group B comprised gymnasts who compete with special rules adapted from the international Code of Points, corresponding to the “Performer” group from AGDP (F.I.G., 1997) whose goal is the refinement and perfection of the previous acquired skills and start with the specialization and acquisition of difficult technical skills, aged 10-13 yr (n=22); and a group C of “Elite Juniors and Seniors”, included gymnasts who compete with the standard international Code of Points and according AGDP (F.I.G., 1997) they should continue with the acquisition of difficult technical skills, refinement and perfection of their technical program and performance delivery, aged ≥ 14 yr (n=4).

Gymnasts from group A only compete at the national level, without special highlight on the individual results, while gymnasts from groups B and C compete in the national or international level, according to their performances and qualification results for specific competitions. In total, six gymnasts belonged to the National Team (2 from group B and 4 from group C).
The Ethical Committee of the Faculty of Sport Sciences from the University of Porto approved this protocol and an informed consent was also obtained from all gymnasts or gymnasts’ parents in agreement with the Declaration of Helsinki of the International Medical Association. The gymnasts’ personal coaches were also informed and their authorization was given.

2.2 Variables and measuring procedures

2.2.1 Anthropometry and body composition

Stature was measured with a stadiometer Seca 202 with an accuracy of 1 mm. Body mass was obtained with a beam balance (Seca) accurate to 0.1 kg. All measurements were taken by the same experienced observer (LA) following the standard procedures as described by Claessens et al. (2008). Body mass index (BMI) was calculated as body mass divided by stature (kg/m²).

Body composition components fat-free mass (FFM, kg) and percentage of body fat mass (Fat, %) were obtained by means of bioelectrical impedance analysis using the Body Composition Analyzer Tanita (Type BC-418 MA). The procedure as described by Heyward and Wagner (2004) was carefully followed.

2.2.2 Skeletal maturity

To estimate skeletal age, the Tanner-Whitehouse TW3-method was used (Tanner, Healy, Goldstein & Cameron, 2001). As the positioning of the hand and wrist is very important, standardized radiographs of the left hand and wrists were taken carefully according to the recommendations as given by Tanner et al. (Tanner et al., 2001). Assessments were made by an orthopedist and a well-trained radiology technician.

2.2.3. Menarcheal status

The maturation level (premenstrual or menstruating) was collected individually by questionnaire. Information regarding the onset of menarche was recorded, to find out if it has occurred or not and the menarcheal ages (Wellens & Malina, 1990).
2.2.4. Ulnar variance determination

Measuring UV of both wrists was done on the same radiographs upon which skeletal maturity was assessed. As positioning of the hand and wrist for estimating skeletal maturity is for the most part the same as for UV determination (i.e., the elbow at 90° flexion and the shoulder at 90° abducted), the use of the same radiographs for both purposes is justified. Because ulnar overgrowth in the immature wrist cannot be measured in the same manner as in adults (Palmer et al., 1982), other reference points were required. The method by Hafner et al. (1989) was thus used. Two UV variables on the left wrist (PRPR-L, mm; DIDI-L, mm) and on the right wrist (PRPR-R, mm; DIDI-R, mm) were determined (Figure 1). PRPR is the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis. DIDI is the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis. For a more detailed description of the method reference is given to Claessens et al. (1996). Positive results, i.e., the respective ulna points are more distally located relative to the respective radius points (ulnar overgrowth), while negative results indicate the opposite. All measurements were taken by the same observer (LA). RX-plates were placed on a negatoscope and UV measurements were taken by means of a transparent plastic template marked with parallel lines 1 mm apart with an amplitude range of 0 to 50 mm.

![Figure 1 - Ulnar variance determination according to the method as described by Hafner et al. (1989).](image)

To assess intra-observer reliability 15 X-rays were marked and measured twice in a blind fashion. There were no significant differences for both variables and
correlations between readings were high, $r = 0.99$ and $r = 0.98$ for PRPR and DIDI respectively.

2.2.5. Training data and handgrip strength determination

Training data such as starting age (chronological age at which formal gymnastics training started) and number of training hours per week (hours/week) were collected individually by interview, with coach’s supervision and checked at the time of data collection. Based on these data was calculated the years of training through the formula: chronological age at present minus their starting age.

Handgrip strength of both left and right hands were measured using a mechanical handgrip dynamometer (Takei Kiki Kogyo - TK 1201) accurate to 0.5 kg. The dynamometer was adjusted to the gymnasts’ hand size to obtain their best performance as prescribed by Balogun, Adenlola, & Akinloye (1991). The subjects were instructed to squeeze the dynamometer’s handle as forceful as possible and to hold it for 5 seconds (Balogun et al., 1991), and three trials for each hand were conducted, alternating hands (Häger-Ross & Rösblad, 2002). Measurements were obtained for both extremities and 2 to 5 minutes of resting intervals were allowed between testing in order to overcome fatigue (Balogun et al., 1991). The highest value (kg) in each side was used to represent handgrip strength (Balogun et al., 1991; Häger-Ross & Rösblad, 2002). All tests were performed by the same observer. To assess intra-observer reliability, 15 gymnasts were evaluated in each hand twice (retest) in a blind fashion within time interval of one week. The correlations between first and second measures were very high ($r = 0.98$ for both right and left hands) representing highly satisfactory results concerning the intra-observer agreement.

2.2.6. Dominance / Handedness

Handedness was assessed based on the preferable hand used in writing (McManus, 1996) and the ambidextrous were excluded. The dominant hand or the rotational direction was determined through the observation of which hand
supports first on the ground when gymnasts perform a cartwheel (Claessens et al., 1998).

2.3. Statistical analyses

Descriptive statistics (Mean ± SD) were calculated for all variables for the total group and for the three subgroups separately. Differences among the three subgroups were analyzed by means of ANOVA with Tuckey Post-Hoc tests.

Absolute (n) and proportional (%) frequency distributions of both UV variables (PRPR and DIDI) of both wrists within three UV categories (negative; neutral; positive) for both the total and the three subgroups were set-up and differences were analyzed by means of the Fisher Exact Test. Classification into the three UV categories was done parallel as those used for adults, i.e., when the relative length of the distal radius and the relative length of the distal ulna differ by less than 1 mm, UV is neutral; when the length of the distal ulna exceeds that of the distal radius by 1 mm or more, UV is considered positive; and when the length of the distal ulna is less than that of the distal radius by 1 mm or more, UV is negative (DiFiori, 2006). These criteria were taken for both the PRPR and DIDI variables.

Right-left differences were analyzed by means of a Wilcoxon test and Spearman correlations.

The relationship between the UV measurements on the one hand and the biological and training characteristics on the other hand were analyzed by means of Spearman correlations.

PASW Statistics 18.0 was used for statistical analyses and α=0.05 was set as significance level. A p-value of ≤ 0.05 was considered statistically significant.

3. Results

Descriptive statistics of all variables for the total sample and for the three subgroups (A, B, and C) of female gymnasts is given in Table 1.
Table 1 - Descriptive statistics (*) and comparisons between groups (**) of biological, training, and ulnar variance characteristics of Portuguese skeletally immature female gymnasts.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total group (n = 33)</th>
<th>Group A (n = 7)</th>
<th>Group B (n = 22)</th>
<th>Group C (n = 4)</th>
<th>F-value</th>
<th>Groups comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biological characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chr. age (yr)</td>
<td>11.1 (2.1)</td>
<td>8.5 (0.7)</td>
<td>11.2 (1.3)</td>
<td>14.9 (0.3)</td>
<td>41.0**</td>
<td>A&lt;B&lt;C</td>
</tr>
<tr>
<td>Skel. age (yr)</td>
<td>10.1 (1.9)</td>
<td>7.8 (1.1)</td>
<td>10.4 (1.5)</td>
<td>12.3 (0.5)</td>
<td>16.9**</td>
<td>A&lt;B&lt;C</td>
</tr>
<tr>
<td>SA – CA (yr)</td>
<td>-0.6 (1.2)</td>
<td>-0.4 (1.2)</td>
<td>-0.3 (1.1)</td>
<td>-2.0 (0.8)</td>
<td>4.0**</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>34.1 (8.3)</td>
<td>24.9 (2.8)</td>
<td>35.4 (7.5)</td>
<td>43.1 (3.2)</td>
<td>11.4**</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>140.0 (11.4)</td>
<td>127.0 (2.9)</td>
<td>142.0 (9.6)</td>
<td>154.0 (2.9)</td>
<td>16.3**</td>
<td>A&lt;B&lt;C</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>17.4 (1.7)</td>
<td>15.8 (1.4)</td>
<td>17.8 (1.8)</td>
<td>18.1 (0.6)</td>
<td>3.1</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>19.5 (2.2)</td>
<td>18.8 (1.8)</td>
<td>20.0 (2.3)</td>
<td>17.9 (1.7)</td>
<td>1.8</td>
<td>A=B=C</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>28.4 (8.8)</td>
<td>16.9 (5.9)</td>
<td>29.4 (6.1)</td>
<td>38.4 (7.9)</td>
<td>13.4**</td>
<td>A&lt;B&lt;C</td>
</tr>
<tr>
<td><strong>Training characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours / week</td>
<td>16.7 (4.3)</td>
<td>15.4 (1.1)</td>
<td>16.5 (4.8)</td>
<td>20.3 (3.8)</td>
<td>1.7</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Starting age (yr)</td>
<td>5.2 (1.3)</td>
<td>4.7 (1.3)</td>
<td>5.1 (1.0)</td>
<td>6.0 (2.2)</td>
<td>1.4</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Years of training</td>
<td>6.1 (2.1)</td>
<td>4.0 (1.3)</td>
<td>6.3 (1.5)</td>
<td>9.0 (2.2)</td>
<td>13.1**</td>
<td>A=B=C</td>
</tr>
<tr>
<td>Handgrip-L (kg)</td>
<td>18.5 (5.8)</td>
<td>12.3 (3.4)</td>
<td>19.6 (5.7)</td>
<td>22.3 (2.7)</td>
<td>6.0**</td>
<td>A&lt;B=C</td>
</tr>
<tr>
<td>Handgrip-R (kg)</td>
<td>19.6 (6.3)</td>
<td>12.8 (3.7)</td>
<td>20.2 (5.8)</td>
<td>26.0 (2.9)</td>
<td>8.1**</td>
<td>A&lt;B=C</td>
</tr>
<tr>
<td><strong>Ulnar variance characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-L (mm)</td>
<td>-1.7 (2.0)</td>
<td>-2.0 (1.4)</td>
<td>-2.0 (1.9)</td>
<td>+0.3 (2.8)</td>
<td>2.4</td>
<td>A=B=C</td>
</tr>
<tr>
<td>DIDI-L (mm)</td>
<td>-2.8 (2.1)</td>
<td>-3.1 (1.5)</td>
<td>-3.2 (1.8)</td>
<td>+0.3 (2.5)</td>
<td>6.3**</td>
<td>A=B=C</td>
</tr>
<tr>
<td>PRPR-R (mm)</td>
<td>-2.2 (2.1)</td>
<td>-2.4 (1.3)</td>
<td>-2.6 (2.0)</td>
<td>-0.3 (3.3)</td>
<td>2.2</td>
<td>A=B=C</td>
</tr>
<tr>
<td>DIDI-R (mm)</td>
<td>-3.1 (2.3)</td>
<td>-3.4 (1.3)</td>
<td>-3.4 (2.4)</td>
<td>-1.0 (2.6)</td>
<td>2.0</td>
<td>A=B=C</td>
</tr>
</tbody>
</table>

(*) results are expressed in Mean (SD); (**) p < 0.05 ANOVA with Tuckey Post-Hoc
Results demonstrate a significant increase in the mean values for chronological age and skeletal age, body mass, stature and fat-free mass from the youngest (Group A) until the oldest (Group C) gymnasts groups. As for the total group skeletal age is, on average, -0.6 ± 1.2 yr behind chronological age, the discrepancy between chronological and skeletal ages becomes more pronounced with increasing age-category, varying from a mean difference of -0.43 ± 1.2 yr (Group A) and -0.3 ± 1.1 yr (Group B) until a mean difference of -2.0 ± 0.8 yr (Group C). No significant differences between groups could be observed for BMI and percentage of body fat.

No significant differences between groups were found both for weekly training hours or practice starting age. As expected, however, there is a significant increase for years of training, varying from 4.0 ± 1.3 yr (Group A) to 9.0 ± 2.2 yr (Group C). For both left and right handgrip strength, a significant lower mean value could be observed for Group A compared to those of Groups B and C.

Concerning the UV measures (DIDI and PRPR, left and right), negative mean values are observed, varying from -3.1 ± 2.3 mm (DIDI-R) until -1.7 ± 2.0 mm (PRPR-L).

However, with increasing age-category, there is a trend that UV becomes more positive. Only for DIDI-L a significant increase (from UV-negative to UV-positive) could be demonstrated between Group A (-3.1 ± 1.5 mm) and Group B (-3.2 ± 1.8 mm) on the one hand, and Group C (+0.3 ± 2.5 mm) on the other hand.

Absolute and proportional frequency distributions within the UV categories (negative, neutral, positive) are given in Table 2.
Table 2 - Absolute (n) and proportional (%) frequency distributions of ulnar variance (UV) categories in Portuguese skeletally immature female gymnasts

<table>
<thead>
<tr>
<th>Group</th>
<th>PRPR-L</th>
<th>PRPR-R</th>
<th>DIDI-L</th>
<th>DIDI-R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>±</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Total group</td>
<td>n=33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>21</td>
<td>10</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>%</td>
<td>63.6</td>
<td>30.3</td>
<td>6.1</td>
<td>66.6</td>
</tr>
<tr>
<td>Group A</td>
<td>n=7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>%</td>
<td>85.7</td>
<td>14.3</td>
<td>0.0</td>
<td>85.7</td>
</tr>
<tr>
<td>Group B</td>
<td>n=22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>14</td>
<td>8</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>%</td>
<td>63.6</td>
<td>36.4</td>
<td>0.0</td>
<td>68.2</td>
</tr>
<tr>
<td>Group C</td>
<td>n=4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>%</td>
<td>25.0</td>
<td>25.0</td>
<td>50.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>

**Fisher Exact Test**
- p-value = 0.02 *
- p-value = 0.11
- p-value = 0.04 *
- p-value = 0.37

* UV negative; + = UV neutral; + = UV positive // * p ≤ 0.05
For the total group of gymnasts, most of the subjects are located within the UV negative category (varying from 63.6% for PRPR-L to 78.8% for both DIDI) and the UV neutral category (varying from 15.2% for DIDI-R to 30.3% for both PRPR). Only 3.0% to 6.1% of the subjects demonstrate a positive UV.

Comparing the distributions between groups, it is clearly seen that there is a significant shift from a mainly negative UV (Group A) to a more neutral and positive UV (Group C) and this for both PRPR and DIDI.

Left-right differences in UV and handgrip strength are given in Table 3.

Table 3 – Left-right differences in ulnar variance and handgrip strength in Portuguese skeletally immature female gymnasts (n=33)

<table>
<thead>
<tr>
<th>Laterality</th>
<th>Left</th>
<th>Right</th>
<th>P</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRPR</td>
<td>-1.7±2.0</td>
<td>-2.2±2.1</td>
<td>0.01*</td>
<td>0.80**</td>
</tr>
<tr>
<td>DIDI</td>
<td>-2.8±2.1</td>
<td>-3.1±2.3</td>
<td>0.14</td>
<td>0.72**</td>
</tr>
<tr>
<td>Handgrip</td>
<td>18.5±5.8</td>
<td>19.6±6.3</td>
<td>0.02*</td>
<td>0.91**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dominance</th>
<th>Left</th>
<th>Right</th>
<th>P</th>
<th>r</th>
<th>Left</th>
<th>Right</th>
<th>P</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRPR</td>
<td>-1.9±1.9</td>
<td>-2.6±2.0</td>
<td>&lt;0.01*</td>
<td>0.85**</td>
<td>-1.4±2.1</td>
<td>-1.7±2.2</td>
<td>0.41</td>
<td>0.77**</td>
</tr>
<tr>
<td>DIDI</td>
<td>-2.7±2.1</td>
<td>-3.4±2.5</td>
<td>0.14</td>
<td>0.60**</td>
<td>-2.9±2.2</td>
<td>-2.8±2.2</td>
<td>0.78</td>
<td>0.90**</td>
</tr>
</tbody>
</table>

*a* Wilcoxon test: *p* ≤ 0.05;  
*b* Spearman correlations: **p* ≤ 0.01

A significant difference between both PRPR measures could be observed, indicating a less negative mean value for PRPR-L compared to PRPR-R, -1.7 mm and -2.2 mm respectively. These differences are also observed when the right hand is dominant, considering both handedness and rotational direction (p<0.01).
For DIDI no significant difference between means could be demonstrated. A relatively high relationship between left and right measures is seen, ranging the respective correlation coefficient from 0.77 to 0.85 (PRPR) and from 0.60 to 0.90 (DIDI).

Right handgrip strength is significant better compared to the left hand, 19.6 kg and 18.5 kg respectively, and a correlation of \( r = 0.91 \) between both hands is noticed.

Correlations between UV measures and biological and training characteristics are mostly rather low and not significant (Table 4).

Table 4- Spearman correlations between ulnar variance, and biological and training characteristics in Portuguese skeletally immature female gymnasts (n = 33)

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRPR-L</th>
<th>PRPR-R</th>
<th>DIDI-L</th>
<th>DIDI-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronological age</td>
<td>0.18</td>
<td>0.09</td>
<td>0.32</td>
<td>0.20</td>
</tr>
<tr>
<td>Skeletal age</td>
<td>0.28**</td>
<td>0.11</td>
<td>0.38*</td>
<td>0.23</td>
</tr>
<tr>
<td>Body mass</td>
<td>0.27</td>
<td>0.16</td>
<td>0.33</td>
<td>0.23</td>
</tr>
<tr>
<td>Stature</td>
<td>0.29</td>
<td>0.16</td>
<td>0.41*</td>
<td>0.27</td>
</tr>
<tr>
<td>BMI</td>
<td>0.22</td>
<td>0.10</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>0.19</td>
<td>0.23</td>
<td>-0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>FFM</td>
<td>0.30</td>
<td>0.09</td>
<td>0.48*</td>
<td>0.20</td>
</tr>
<tr>
<td>Training characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours/week</td>
<td>0.23</td>
<td>0.20</td>
<td>0.28</td>
<td>0.27</td>
</tr>
<tr>
<td>Starting age</td>
<td>0.10</td>
<td>-0.05</td>
<td>0.20</td>
<td>-0.10</td>
</tr>
<tr>
<td>Years of training</td>
<td>0.10</td>
<td>0.10</td>
<td>0.13</td>
<td>0.22</td>
</tr>
<tr>
<td>Handgrip-L</td>
<td>0.23</td>
<td>0.06</td>
<td>0.32</td>
<td>0.22</td>
</tr>
<tr>
<td>Handgrip-R</td>
<td>0.11</td>
<td>-0.07</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>Ulnar variance characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-L</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-R</td>
<td>0.80**</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIDI-L</td>
<td>0.72**</td>
<td>0.68**</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DIDI-R</td>
<td>0.73**</td>
<td>0.84**</td>
<td>0.72**</td>
<td>-</td>
</tr>
</tbody>
</table>

* \( p \leq 0.05 \); ** \( p \leq 0.01 \)

Significant (\( p \leq 0.05 \)), but relatively low correlations were observed only between DIDI-L and skeletal age (\( r = 0.38 \)); stature (\( r = 0.41 \)) and FFM (\( r = 0.48 \)).
Relative high correlations are seen between the four UV variables, varying from $r = 0.68$ (DIDI-L and PRPR-R) and $r = 0.84$ (DIDI-R and PRPR-R).

4. Discussion

Due to the absence of Portuguese references or normative data for the measurement of UV, the gymnasts’ characteristics were compared with a group of young Portuguese girls studied by Maia et al. (2007) with a similar age to our sample. When comparing the female gymnasts under study with reference data for Portuguese girls (Maia et al., 2007), it is clearly demonstrated that the female gymnasts are, on average, considerably smaller and have a lower body weight and BMI when compared with nonathlete girls of the same chronological age, as shown in Table 5.
experimental work

Ulnar variance in female gymnasts

Table 5 - Means for body mass, stature, BMI, and handgrip-R of Portuguese female gymnasts, percentiles (P) of the nonathlete reference data to which means of gymnasts correspond, and reference medians for Portuguese girls (Maia et al., 2007).

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gymnasts</td>
<td>Reference</td>
<td>Gymnasts</td>
</tr>
<tr>
<td>Chr. age (yr)</td>
<td>Mean (n=7)</td>
<td>P (n=699)</td>
<td>Mean (n=22)</td>
</tr>
<tr>
<td></td>
<td>8.5</td>
<td>9.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>24.9</td>
<td>P10-P25</td>
<td>30.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>127.0</td>
<td>P10-P25</td>
<td>131.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>142.0</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>15.8</td>
<td>P10-P25</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handgrip-R (kg)</td>
<td>12.8</td>
<td>P50-P75</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P = percentile (percentile values made from the statistical-mathematical model presented by Cole & Green, 1992)
Mean body mass of the gymnasts range from Percentile (P) 3 to P50 and mean stature range from P10 to P50. Note that the older gymnasts (Group C) have values below the percentile values observed in group B and similar percentile values were observed for BMI. Concerning handgrip strength the mean values from gymnasts are situated around the P50 and P90, indicating that these smaller-sized and late-maturing gymnasts have developed an exceptional level of arm muscle strength. Although the small number of 4 individuals which comprise the group C, it is representative of gymnasts’ population in Portugal, since it includes all the skeletally immature gymnasts with more than 14 years old (junior and senior).

These observations are in correspondence with other studies on female gymnasts as compared to reference data (Claessens et al., 1992; Claessens et al., 1991). Our gymnasts’ sample is representative of the immature female gymnasts competing in Portugal. Their training is initiated at very early ages (5.2 ± 1.3 yr), before skeletal maturation as occurred. As advocated by some authors (Baxter-Jones & Maffulli, 2003; Malina, Bouchard & Bar-Or, 2004), during childhood, gymnasts’ skeletal ages are average or on time for chronological age. For whole group the mean difference between skeletal and chronological age was –0.55 ± 1.2 yr (on time). As most gymnasts who enter in the adolescence are classified as average and late-maturing, with few early-maturing girls and in later adolescence, most gymnasts are classified as late-maturing (Baxter-Jones & Maffulli, 2003). According to the definition from Tanner et al. (2001), the average of skeletal age increase is one year per chronological age’s year. In our gymnasts skeletal age tends to lag relative to chronological age and there were significant differences between chronological and skeletal ages in the three age groups (p = 0.03), tending to be late-maturing with increasing of age. Relatively to the mean values between groups, groups A and B are similar and significantly different from group C (-0.43 yr and -0.32 to -2.00 yr, respectively).

Comparing the Portuguese gymnasts with world-top, elite female gymnasts (Claessens et al., 1991; Daly et al., 2001; Webb & Rettig, 2008), it is demonstrated that our gymnasts are, on average, both younger and training
well below the elite level. For example, while elite gymnasts participating at World Championships train, on average, 27 hours/week (from 13 to 48h) (Caine et al. 1996), the Portuguese gymnasts train 16.7 hours/week. It is thus clear that our group is, on average, of nonelite caliber, as could be expected in view of the younger age of the girls categorized in the gymnastics’ level of both Group A (beginners/advanced) and Group B (performers). On the other hand, the training data of gymnasts from Group C, who belong national team and competes in international events, are well in correspondence with those of world-top level gymnasts related to starting age (6.0 yr versus 7.1 yr) and years of training (9.0 yr versus 8.8 yr). Therefore, this group of 4 gymnasts can be labeled as elite, although train fewer hours/week (20.3 ± 3.8) when compared to world-top gymnasts.

Gymnastics combines an intense level of participation and a high-physiologic loading of the upper extremities (Gabel, 1998). The primary focus of this combination of events is at the wrist, which, in the gymnast has high an incidence of clinical disorders as any other region (Gabel, 1998). Artistic Gymnastics has been studied extensively as a model for the skeletal effects of impact loading (Dowthwaite & Scerpella, 2009). Gymnastics expose the wrist to considerable loads, by axial compression and bending forces during tumbling, vaulting and beam work (Dowthwaite & Scerpella, 2009). The distal radius physis is a common site for injury in gymnasts because of the significant amount of load applied during upper extremity weight-bearing (Webb & Rettig, 2008). Causal relationships between UV and wrist disorders are known (Sönmez et al., 2002). For Mandelbaum et al. (1989) and Chang et al. (1995) the repetitive loads in the radial epiphysis before skeletal maturity leads to a premature closure of the growth plate and consequently a predisposition to positive UV.

Supposedly one would expect that biologic and trainability variables - such as age, body composition and hours of training, starting age, years of training and handgrip strength - could influence UV.

Although the total group of Portuguese female gymnasts showed, on average, negative UV (measures for both DIDI and PRPR, varying from -3.1 ± 2.3 mm
DIDI-R until $-1.7 \pm 2.0$ mm PRPR-L), it is demonstrated that with increasing age, UV becomes more positive. Gymnasts skeletally more advanced in their maturity status tend to exhibit an ulnar overgrowth (Beunen et al., 1999) or a greater risk of developing positive UV (Claessens et al., 1996). However, Hafner et al. (1989) didn’t find significant differences in mean variance across the skeletal age spectrum for either adolescents’ boys or girls or even in female gymnasts (Beunen et al., 1999).

This trend is in full agreement with previous studies in young male and female gymnasts as illustrated in Table 6.
### Experimental Work

#### Ulnar variance in female gymnasts

Table 6 - Overview of ulnar variance (PRPR) measurements in young male and female gymnasts

<table>
<thead>
<tr>
<th>Reference</th>
<th>Population</th>
<th>N</th>
<th>Gender</th>
<th>Mean age (yr)</th>
<th>Skill / level</th>
<th>UV method</th>
<th>Mean UV (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hafner et al. (1989)</td>
<td>535</td>
<td>M+F</td>
<td></td>
<td>1-15 (Range)</td>
<td>Reference data</td>
<td>Hafner (PRPR)</td>
<td>-2.1 / -2.3</td>
</tr>
<tr>
<td><strong>Gymnasts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chang et al. (1995)</td>
<td>176</td>
<td>M+F</td>
<td></td>
<td>13.1</td>
<td>Chinese opera students</td>
<td>Perpendicular</td>
<td>+0.07</td>
</tr>
<tr>
<td>Claessens et al. (1996)</td>
<td>156</td>
<td>F</td>
<td></td>
<td>15.9</td>
<td>World-top gymnasts</td>
<td>Hafner (PRPR-L)</td>
<td>+0.50</td>
</tr>
<tr>
<td>DiFiori et al. (1997)</td>
<td>44</td>
<td>M+F</td>
<td></td>
<td>11.6</td>
<td>Nonelite gymnasts (USA)</td>
<td>Hafner (PRPR)</td>
<td>-1.3</td>
</tr>
<tr>
<td>DiFiori et al. (2002)</td>
<td>59</td>
<td>M+F</td>
<td></td>
<td>9.3</td>
<td>Nonelite gymnasts (USA)</td>
<td>Hafner (PRPR)</td>
<td>-1.7</td>
</tr>
<tr>
<td>Claessens et al. (1998)</td>
<td>36</td>
<td>F</td>
<td></td>
<td>6-14 (Range)</td>
<td>Nonelite gymnasts (Flemish / Belgium)</td>
<td>Hafner (PRPR-L)</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hafner (PRPR-R)</td>
<td>-1.6</td>
</tr>
<tr>
<td>Dwek et al. (2009)</td>
<td>10</td>
<td>F</td>
<td></td>
<td>14.2</td>
<td>Nonelite gymnasts (USA)</td>
<td>Hafner (PRPR) (Measured on MRI)</td>
<td>-0.18</td>
</tr>
<tr>
<td>This study</td>
<td>7</td>
<td>F</td>
<td></td>
<td>8.5</td>
<td>Nonelite gymnasts (Portugal)</td>
<td>Hafner (PRPR-L)</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hafner (PRPR-R)</td>
<td>-2.4</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>F</td>
<td></td>
<td>11.2</td>
<td>Nonelite gymnasts (Portugal)</td>
<td>Hafner (PRPR-L)</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hafner (PRPR-R)</td>
<td>-2.6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>F</td>
<td></td>
<td>14.9</td>
<td>'Elite' gymnasts (Portugal)</td>
<td>Hafner (PRPR-L)</td>
<td>+0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hafner (PRPR-R)</td>
<td>-0.3</td>
</tr>
</tbody>
</table>

*a The method *Hafner* refers to Hafner et al. (1989) / *PRPR* refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / *PRPR-L* and *PRPR-R* refers to the results obtained on the left and right X-rays respectively / *Perpendicular* refers to the method described by Steyers and Blair (1989).*
Mean PRPR measurements obtained in skeletally immature gymnasts range from -2.6 mm (PRPR-R) in Portuguese nonelite female gymnasts (n = 22) to +0.5 mm (PRPR-L) in 156 world-top female gymnasts, clearly demonstrating that the higher the gymnastics’ level, the more positive PRPR measure is seen. Also within our Portuguese sample of female gymnasts a more positive PRPR result is obtained for the more elite gymnasts of Group C, compared to the other lower-level gymnasts of Group A and Group B. The shift from a negative UV to a more positive UV with increasing age is also clearly illustrated by the proportional frequency distributions of UV within the three UV categories (negative, neutral, positive) as shown in Table 7.

Table 7- Proportional (%) frequency distribution of ulnar variance categories in immature world-top female gymnasts and Portuguese gymnasts

<table>
<thead>
<tr>
<th>UV – category</th>
<th>World-top gymnasts (n=156) a</th>
<th>Portuguese gymnasts (n=33) b</th>
<th>Portuguese gymnasts (n=4) c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIDI-L PRPR-L</td>
<td>DIDI-L PRPR-L</td>
<td>DIDI-L PRPR-L</td>
</tr>
<tr>
<td>Negative</td>
<td>57.1 26.3</td>
<td>78.8 63.6</td>
<td>25.0 25.0</td>
</tr>
<tr>
<td>Neutral</td>
<td>23.1 28.2</td>
<td>18.2 30.3</td>
<td>50.0 25.0</td>
</tr>
<tr>
<td>Positive</td>
<td>19.8 45.5</td>
<td>3.0  6.1</td>
<td>25.0 50.0</td>
</tr>
</tbody>
</table>

a Claessens et al. (1996); b This study: total group; c This study: Group C

It can be seen that the higher the age-category - and thus also the higher competition level - the more similar the distributions within the three categories are, especially for the PRPR measure of UV with percentages around 25%; 25% to 28%; and 45% to 50%, for the negative, neutral and positive UV categories, respectively. UV in gymnasts’ wrists was significantly more positive than the general population but within the normal range (DiFiori et al., 2002a; Dwek et al., 2009). Although such a trend can be indicative for the negative influence of gymnastic training on the UV phenomenon, there is no proof that a causal relationship exist between both, the volume of gymnastic training and the UV, because of the cross-sectional design of the studies under consideration. Longitudinal studies are more appropriate to prove the causal relationship between training and UV outcomes. However, up till now there are only a few
longitudinal studies of UV in young gymnasts, whereby different trends in the development of UV have been noted (Claessens et al., 1997; DiFiori, 2006; DiFiori et al., 2001). In a study of Claessens et al. (1997) a negative UV is reported that becomes more pronounced with increasing age during a 4- to 5-year follow-up of 36 Flemish nonelite female gymnasts 6 to 14 years of age. In contrast, DiFiori et al. (2001, 2006) observed a mean negative UV at baseline which became significantly more positive than age-appropriate normative values in 28 USA male and female gymnasts, 5 - 16 years of age, during three years of follow-up. It is clear that more longitudinal research is needed to unravel the relationship between gymnastic training and the extent of the UV measures.

Comparisons among gymnasts have indicated that positive UV is more frequent in gymnasts who are older, are taller, heavier and more muscular, and have more years of training, although the latter observation is not unequivocal (DiFiori, 2006). These findings are also observed in our Portuguese sample of skeletally immature female gymnasts, whereby significant, but rather low, correlations were found between DIDI-L and skeletal age ($r = 0.38$); stature ($r = 0.41$) and fat-free mass ($r = 0.48$). No significant correlations are observed between UV and training variables. This is in full agreement with the results obtained by Claessens et al. (1996) in 156 immature elite female gymnasts participating at world championships, whereby significant, but also low, correlations between DIDI (also measured on the left wrist) and stature ($r = 0.23$); body weight ($r = 0.21$); muscle development ($r = 0.25$); and TW2-skeletal age ($r = 0.16$) could be observed. Also in this group of highly trained world-top gymnasts, neither training history, nor performance scores obtained during the championships were significantly related to UV ($r$ varying from -0.11 to 0.15).

Looking to the correlation results between UV and somatic and training characteristics more in detail (Table 4), it is demonstrated that significant correlations could be observed with only one UV measure, namely DIDI obtained on the X-ray of the left wrist. With the other UV measures, DIDI-R, and PRPR-L and PRPR-R, no significant correlations were obtained. It is also seen that the correlations for the four UV measures are not of the same magnitude. PRPR measure is more related to the shape of the bone, whereas DIDI is more
representative of differences in bone growth concerning ulnar length relative to the radius length (Claessens et al., 1998). This is not only true for the interrelationships between UV and some risk factors, but also for the absolute mean outcomes of both UV measures, PRPR and DIDI, as already demonstrated in previous studies (Table 8).
### Experimental Work

*Ulnar variance in female gymnasts*

Table 8- Overview of left-right difference of ulnar variance (PRPR) measurements

<table>
<thead>
<tr>
<th>Reference</th>
<th>Population</th>
<th>Method ¹</th>
<th>Left site (mm)</th>
<th>Right site (mm)</th>
<th>Difference (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiFiori et al. (1997)</td>
<td>2 ≤ 6 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-1.0</td>
<td>-1.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>30 7-13 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-2.0</td>
<td>-2.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>12 14-15 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>-1.6</td>
<td>-1.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Claessens et al. (1998)</td>
<td>36 8-14 / F nonelite gymnasts</td>
<td>PRPR</td>
<td>-0.8</td>
<td>-1.6</td>
<td>0.8 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DIDI</td>
<td>-4.9</td>
<td>-4.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Freedman et al. (1998)</td>
<td>100 19-61 / M+F adult reference data</td>
<td>Perpendicular</td>
<td>-0.13</td>
<td>-0.29</td>
<td>0.16</td>
</tr>
<tr>
<td>DiFiori et al. (2002)</td>
<td>59 5-16 / M+F nonelite gymnasts</td>
<td>PRPR</td>
<td>?</td>
<td>?</td>
<td>0.7</td>
</tr>
<tr>
<td>This study</td>
<td>33 7-15 / F nonelite gymnasts</td>
<td>PRPR</td>
<td>-1.7</td>
<td>-2.2</td>
<td>0.5*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DIDI</td>
<td>-2.8</td>
<td>-3.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

¹ PRPR and DIDI refers to the method of Hafner et al. (1989) / PRPR refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / DIDI refers to the measurement obtained using the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis / Perpendicular refers to the method described by Steyers and Blair (1989).

* p ≤ 0.05
Differences between left and right measures of UV vary between 0.0 mm observed for the PRPR measure in 14-15 year old nonelite USA male and female gymnasts (DiFiori et al., 1997) to 0.8 mm for the PRPR measure in 8-14 year old nonelite Flemish female gymnasts (Claessens et al., 1998). As can be seen, higher UV mean values, although not always significantly, are obtained when measured on the right wrist compared to those obtained on the left wrist, with the exception of the DIDI measure in the nonelite group of gymnasts as studied by Claessens et al. (1998) where a higher but not significant mean value can be noted for the left wrist.

There is no consensus in literature regarding the concept of dominance. Some authors referred to dominance as handedness, i.e. the hand used preferentially or performance hand (McManus, 1996), while others consider lateral preference the way (direction) a subject execute their whole body spontaneous turns (Golomer, Rosey, Dizac, Mertz & Fagard, 2009). In our study, we have considered the dominance as the hand first set on the ground while performing a cartwheel (Claessens et al., 1998).

The gymnasts’ choice of the supporting hand during a cartwheel may exploit some biomechanical properties in order to facilitate some tasks. Turning preference in gymnastics depends on the demands of tasks and, in part, on lateral preference (Heinen, Vinken & Velentzas, 2010). The systematic repeat of certain movements and the effect of these loads in the most regularly used hand/wrist (dominant hand), is likely to induce changes in UV.

In our sample, there are significant differences between left and right values in PRPR (p = 0.01). These differences are also observed when the right hand is dominant, considering both handedness and dominance (p<0.01). The UV values from both sides have strong associations between them (r from 0.60 to 0.85), except when observed the left dominant individuals which present differences in the results related just with handedness. Freedman et al. (1998) didn’t find a significant correlation between UV and handedness in a research with adult reference data. Additionally, DiFiori et al. (2002a) in a study involving 59 gymnasts (28 girls and 31 boys, with an average age of 9.3 years), and in spite of a mean side-to-side UV difference of 0.7 ± 0.6 mm, also couldn’t find an
association with hand dominance. Concerning dominance, Claessens et al. (1998) assessed X-rays in dominant left and right hands of 36 female gymnasts and the results were later compared with data obtained from the non-dominant side of the same gymnasts. They did not observe significant differences in UV between dominant and non-dominant wrists ($p = 0.22$ to PRPR and $p = 0.08$ to DIDI) and concluded that the UV phenomenon is not only related to gymnastics training.

Due to the observed differences between UV obtained on the left and right wrists, and the different correlation results obtained between these UV measures and other characteristics such as age, sex, training and performance history, and physical examination findings, it is clear that in future studies the measurement of UV of both wrists is recommended and should specify the manual dominance, to unravel the complex phenomenon of the problematic nature of UV.

5. Conclusions

The main results of this study do not directly support the thesis that gymnastics training or handgrip strength are associated with UV. Nevertheless, some significant results were found such as the differences between right and left UV and the correlations between UV and some biological characteristics (skeletal age, stature and fat-free mass).
Unar Variance Related to Biological and Training Characteristics, Pain and Handgrip Strength in Portuguese Skeletally Immature Male Gymnasts

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Running head: Ulnar Variance in Portuguese Male Gymnasts

Keywords: Gymnasts; Ulnar variance; Training; Pain

Under review: 2012.
Abstract

The purpose of this study was to investigate the association between Ulnar Variance (UV) and biological and training characteristics, handgrip and wrist pain in a group of twenty-three Portuguese skeletally immature male gymnasts (aged 11.2 ± 2.5 yr).

Left and right UV was obtained using Hafner’s procedure and skeletal age was determined by the Tanner-Whitehouse 3-method. A negative mean value for UV measures was observed (-2.4 to -3.6 mm) without significant differences with increasing age-category (p = 0.09 to p = 0.48). Significant low correlations were observed between some UV parameters and stature, fat%, years of training and left handgrip strength. Ten gymnasts reported wrist pain with gradual onset and UV values were very similar between painless and painful wrists.

Results of this study do not directly support the thesis that gymnastics training and biological variables or wrist pain are associated with UV.
1. Introduction

Artistic gymnastics (AG) is a sport characterized by involvement at an early age (Caine et al., 2006; Claessens, 2004; Daly et al., 2001), with a relatively rapid transition to high-volume, high-impact training (Caine & Nassar, 2005; Daly et al., 2001).

AG requires long hours of practice and repetitions of movements (Dwek et al., 2009), as well as high ability of strength, flexibility and balance to learn complex and high level skills (Zetaruk, 2000). It is unique among all athletic endeavors in the demands it places on the upper extremities (Markolf et al., 1990). AG requires conversion of the upper limb into load-bearing extremities, leading to upper extremity injuries, especially on the wrists (Caine et al., 1992; Claessens et al., 1997; Webb & Rettig, 2008). In fact, since nearly all gymnasts enter the sport at a young age, the wrist growth plates are potential sites for injuries (Caine et al., 2006; DiFiori et al., 2006; DiFiori et al., 2002a). The immature musculoskeletal system, submitted to repetitive biomechanical stress, becomes more vulnerable and may lead to overuse injuries (Cornwall, 2010; Kerssemakers et al., 2009; Zetaruk, 2000). Repetitive trauma to the radial physis can lead to a premature partial or complete closure of the growth plate or retarded radial growth (Caine et al., 1992; Gerbino, 1998). It has also been theorized that the increased loading during growth and development of the distal radial physis will result in wrist pain (DiFiori et al., 2006; DiFiori, Puffer, Mandelbaum & Mar, 1996), in length discrepancy (Caine et al., 2006) and an increased incidence of positive ulnar variance (UV) (De Smet et al., 1994; DiFiori et al., 2006; Markolf et al., 1990), which are ‘gymnastics-specific’ characteristics (Chang et al., 1995; Dwek et al., 2009).

Male gymnasts present more injuries at the upper limbs in contrast to the female (Chang et al., 1995; Dixon & Fricker, 1993; Kirialanis et al., 2002), probably due to the fact that men’s gymnastics is comprised by six apparatus, all of which producing load on the wrists (Markolf et al., 1990).

Little is known about the relationship between wrist injuries, more specifically UV, and arm muscle strength, hand dominance and wrist pain. Wrist pain is common among both elite and non-elite male gymnasts (Caine et al., 1992;
DiFiori et al., 1996), although the specific etiology is often difficult to determine (DiFiori & Mandelbaum, 1996; Gerbino, 1998). Eventually, there might be a certain predisposition for the occurrence of injuries in a particular side (Sands et al., 1993), which may reflect the fact that gymnasts have a preferred side when performing (Fellander-Tsai & Wredmark, 1995). Some authors state that UV can vary from side to side in an individual, resulting in significant right-left differences (Claessens, 2001; DiFiori, 2006; DiFiori et al., 2002a; Freedman et al., 1998).

Studies concerning the impact of gymnastic training on the UV phenomenon are mostly concentrated on female gymnasts. Studies on male gymnasts are rather scarce, and the obtained results are univocal.

The purposes of this study were: (a) to evaluate the impact of training and biological characteristics on the UV in Portuguese skeletally immature male gymnasts; and (b) to consider wrist pain status in relation with UV and handgrip strength in this group of gymnasts.

2. Methods

2.1. Subjects

The sample consisted of 23 Portuguese skeletally immature male artistic gymnasts varying in chronological age from 7.2 yr until 16.0 yr, with a mean age of 11.2 ± 2.5 yr.

All gymnasts compete at national and/or international level and were recruited from several clubs situated around the cities Porto and Lisbon. Initially the total group was divided in 3 subgroups according to their age: a group of ‘Beginners/Advanced’, aged 6-10 yr (group A, n = 9); a group of ‘Performers’, aged 11-14 yr (group B, n = 12); and a group of ‘Elite Juniors and Seniors’, aged ≥ 15 yr (group C, n = 2), according the competition levels defined by the Portuguese Federation of Gymnastics (FGP) which is in accordance to the ‘Age Group Development Program’ (AGDP) from the International Gymnastics Federation (F.I.G., 1997). However, in order to avoid analyses and comparisons with a very small group of two individuals, it was decided to include the two
gymnasts from Elite Juniors/Seniors into group B. In this context the total sample was divided in 2 subgroups (group A, n = 9 and group B, n = 14).

The Ethical Committee of the Faculty of Sport Sciences from the University of Porto approved this protocol and an informed consent was also obtained from all gymnasts or gymnasts’ parents. The gymnasts’ personal coaches were also informed and their authorization was given.

2.2. Variables and measuring procedures

2.2.1. Anthropometry and body composition

Stature was measured with a stadiometer Seca 202 with an accuracy of 1 mm. Body mass was obtained with a scale (Seca) accurate to 0.1 kg. Measurements were taken by the same experienced observer (LA) following the procedures described by Claessens et al. (2008). Body mass index (BMI) was calculated as body mass divided by stature (kg/m²).

Body composition components fat-free mass (FFM, kg) and percentage of body fat mass (Fat, %) were obtained by means of bio-electrical impedance analysis using the Body Composition Analyzer Tanita (Type BC-418 MA). This device takes into account chronological age of the subjects and the guidelines suggest categorizing individuals into two activity levels: standard and athlete (Volgyi, Tylavsky, Lyytikainen, Suominen, Alen, & Cheng, 2008). All our gymnasts were classified as standard because according to those guidelines only individuals older than 17 years can be categorized as athletes.

2.2.2. Skeletal maturity

Maturity status refers to the individual’s state of maturation at a given point in time, specifically by the skeletal age (SA) attained at a specific chronological age (CA) (Malina et al., 2004; Malina et al., 2006). Skeletal maturity is equivalent to the difference between SA and CA (SA-CA) and it can be advanced or early maturing (above 1.0 year), delayed or late maturing (below 1.0 year) and ‘on time’ or in average maturing (within ± 1 year) (Malina et al., 2004). Based on the above criteria subjects are classified as mature or immature depending of the union or fusion of epiphysis with their respective diaphysis.
To estimate SA, the Tanner-Whitehouse TW3-method was used, with the radius, ulna, and short (RUS) bone system (Tanner et al., 2001). Standardized radiographs of the left hand and wrists were taken according to the recommendations given by Tanner et al. (2001). SA assessment was made by an orthopedist with experience in the TW3-method. To assess intra-observer reliability 15 wrists were measured twice and the intra-class correlation coefficient was very high (R=0.999, 95% CI = 0.998 to 1.000).

2.2.3. Ulnar variance determination

Because positioning of the hand and wrist for estimating skeletal maturity is for the most part the same as for UV determination (i.e., the elbow at 90° flexion and the shoulder at 90° abducted), the use of the same radiographs for both purposes is justified. UV measuring was done on both right and left radiographs by means of the method of Hafner et al. (1989) for immature subjects. Two ulnar variance variables on the left wrist (PRPR-L, mm; DIDI-L, mm) and on the right wrist (PRPR-R, mm; DIDI-R, mm) were determined. PRPR is the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis. DIDI is the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis. For a detailed description of the method, reference is given to Claessens et al. (1996).

The subjects classification into the three UV categories was carried out similarly to the classification conducted for adults: (a) when the relative length of the distal radius and the relative length of the distal ulna differed by less than 1 mm, UV was considered neutral; (b) when the length of the distal ulna exceeded that of the distal radius by 1 mm or more, UV was considered positive; (c) when the length of the distal ulna was inferior to that of the distal radius by 1 mm or more, UV was classified as negative (DiFiori, 2006). Positive UV means that the respective ulna points are more distally located relative to the respective radius points (ulnar overgrowth), while negative UV indicates the opposite.

All measurements were taken by the same observer (LA). To assess intra-observer reliability 15 X-rays were marked and measured twice in a blind fashion. There were no significant differences for both variables and intra-class
correlations between readings were high, $R = 0.971$, 95% CI = 0.912 to 0.991 for DIDI and $R = 0.987$, 95% CI = 0.962 to 0.996 for PRPR.

2.2.4. Training data, handgrip strength

Training data such as ‘starting age’ (i.e., the chronological age at which formal gymnastic training started) and number of ‘training hours per week’ (h/week) were collected individually by interview and checked by the main researcher at the time of data collection. ‘Years of training’ was calculated from the subjects’ chronological age at present minus his starting age.

Handgrip strength of both left and right hands were measured using a mechanical handgrip dynamometer (Takei Kiki Kogyo - TK 1201) accurate to 0.5 kg. The dynamometer was adjusted to the gymnasts’ hand size to obtain their best performance as prescribed by Schlüssel et al. (2008). The subjects were instructed to squeeze the dynamometer’s handle as forceful as possible and to hold it for 5 seconds. Three trials for each hand were conducted, alternating hands (Schlüessel et al., 2008). The highest value in each side (kg) was used to represent handgrip strength (Balogun et al., 1991; Schlüssel et al., 2008). All tests were supervised by the same observer. To assess intra-observer reliability, 15 gymnasts were evaluated in each hand twice (retest) in a blind fashion within a time interval of one week. The intra-class correlations between first and second measures were very high ($R = 0.990$, 95% IC = 0.972 to 0.997).

2.2.5. Pain information

Each gymnast completed an interview-based questionnaire detailed history and description of wrist pain: existence, limitation and in which apparatus they felt it. Gymnasts were asked if they had any pain in their wrists in the moment of data collection. Gymnasts who answered “yes”, they were then asked to clarify the nature of the pain onset (sudden or gradual), and those with traumatic history (acute wrist injury) were excluded from the analyzed data. Depending on the dysfunction caused by wrist pain, the gymnasts were divided into different categories according to their functional classification based upon both subjective and objective measures (DiFiori et al., 1996; DiFiori et al., 2002b):
grade 1, unrestricted; grade 2, attends all training sessions, but unable to full work; grade 3, misses at least one training session per month; and grade 4, unable to participate.

2.3. Data analysis

Descriptive statistics (mean ± SD) were calculated for all variables for whole group and for the two subgroups, separately. Differences among the three subgroups were calculated using Man-Whitney test.

Absolute (n) and proportional (%) frequency distributions of both UV variables (PRPR and DIDI) of both wrists within three UV categories (negative; neutral; positive), for both the total and the two subgroups, were set-up and the differences were analyzed by means of the Chi-Square test.

The Mann-Whitney Test was used to evaluate the differences of UV values in painful or painless wrists, and to evaluate de difference between groups in all variables.

A t-test was used to compare the UV values with normative data from the general population.

The relationship between the UV measurements, on one hand, and the biological and training characteristics, on the other hand, were analyzed by means of partial correlations, adjusted for chronological age (CA), skeletal age (SA) and the difference between SA and CA (SA-CA). PASW Statistics 19.0 was used for statistical analyses and a p-value of ≤ 0.05 was considered as statistically significant.

3. Results

Descriptive statistics of all variables of the total sample and the three subgroups (A, B, and C) are given in Table 1.
Table 1 - Descriptive statistics (Mean ± SD) and comparison between groups of biological, training, and ulnar variance characteristics from Portuguese skeletally immature male gymnasts.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total sample (n = 23)</th>
<th>Group A (n = 9)</th>
<th>Group B (n = 14)</th>
<th>Z</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biological characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chr. age (yr)</td>
<td>11.2 ± 2.5</td>
<td>8.6 ± 1.0</td>
<td>12.8 ± 1.7</td>
<td>-3.97</td>
<td>0.00*</td>
</tr>
<tr>
<td>Skeletal age (yr)</td>
<td>10.3 ± 2.0</td>
<td>8.2 ± 0.9</td>
<td>11.7 ± 1.0</td>
<td>-3.97</td>
<td>0.00*</td>
</tr>
<tr>
<td>SA – CA (yr)</td>
<td>-0.9 ± 1.1</td>
<td>-0.5 ± 0.8</td>
<td>-1.1 ± 1.2</td>
<td>-1.39</td>
<td>0.17</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>35.8 ± 8.5</td>
<td>28.3 ± 3.7</td>
<td>40.6 ± 7.1</td>
<td>-3.65</td>
<td>0.00*</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>141.7 ± 12.0</td>
<td>130.6 ± 5.4</td>
<td>148.8 ± 9.2</td>
<td>-3.94</td>
<td>0.00*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.3 ± 1.5</td>
<td>16.4 ± 1.1</td>
<td>17.9 ± 1.5</td>
<td>-2.35</td>
<td>0.02*</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>15.4 ± 2.5</td>
<td>17.3 ± 1.8</td>
<td>13.9 ± 1.8</td>
<td>-3.23</td>
<td>0.00*</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>29.0 ± 8.3</td>
<td>23.4 ± 2.9</td>
<td>33.2 ± 8.6</td>
<td>-3.13</td>
<td>0.00*</td>
</tr>
<tr>
<td><strong>Training characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours / week</td>
<td>17.8 ± 3.9</td>
<td>14.1 ± 2.8</td>
<td>20.1 ± 2.5</td>
<td>-3.81</td>
<td>0.00*</td>
</tr>
<tr>
<td>Starting age (yr)</td>
<td>6.0 ± 1.9</td>
<td>6.0 ± 2.1</td>
<td>6.1 ± 1.9</td>
<td>-0.13</td>
<td>0.90</td>
</tr>
<tr>
<td>Years of training</td>
<td>5.4 ± 3.0</td>
<td>2.9 ± 1.7</td>
<td>6.9 ± 2.5</td>
<td>-3.32</td>
<td>0.00*</td>
</tr>
<tr>
<td>Handgrip-L (kg)</td>
<td>21.4 ± 7.2</td>
<td>14.9 ± 3.5</td>
<td>25.6 ± 5.6</td>
<td>-3.85</td>
<td>0.00*</td>
</tr>
<tr>
<td>Handgrip-R (kg)</td>
<td>22.2 ± 6.9</td>
<td>16.1 ± 2.7</td>
<td>26.2 ± 5.7</td>
<td>-3.98</td>
<td>0.00*</td>
</tr>
<tr>
<td><strong>Ulnar variance characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-L (mm)</td>
<td>-2.4 ± 1.4</td>
<td>-1.9 ± 1.7</td>
<td>-2.8 ± 1.5</td>
<td>-1.54</td>
<td>0.12</td>
</tr>
<tr>
<td>DIDI-L (mm)</td>
<td>-3.1 ± 2.2</td>
<td>-3.1 ± 1.1</td>
<td>-3.1 ± 2.7</td>
<td>-0.71</td>
<td>0.48</td>
</tr>
<tr>
<td>PRPR-R (mm)</td>
<td>-2.8 ± 1.5</td>
<td>-2.3 ± 0.9</td>
<td>-3.1 ± 1.8</td>
<td>-1.68</td>
<td>0.09</td>
</tr>
<tr>
<td>DIDI-R (mm)</td>
<td>-3.6 ± 1.7</td>
<td>-4.0 ± 1.0</td>
<td>-3.3 ± 2.9</td>
<td>-0.74</td>
<td>0.46</td>
</tr>
</tbody>
</table>

a Mann-Whitney test: * p < 0.05

The results demonstrate significant differences in the mean values between groups A and B in biological and training characteristics (p ≤ 0.05), with group B showing the higher values, with the exception of a decrease in the mean values of Fat (%). No significant difference between groups was observed for starting age, which remained approximately 6.0 years for both groups (p = 0.90). Regarding the difference between skeletal and chronological age (SA-CA), no significant differences could be observed between both groups (-0.5 ± 0.8 and -1.1 ± 1.2; p = 0.17).

Concerning the UV measures (DIDI and PRPR, left and right), only negative mean values were observed, varying from -3.6 ± 1.7 mm (DIDI-R) to -2.4 ± 1.4
mm (PRPR-L) in the whole sample, with no significant differences between groups (p = 0.09 to p = 0.48).

Table 2 shows no significant differences in UV values in our sample of male gymnasts grouped as late, on time, and early maturing as determined by SA minus CA.

Table 2- Ulnar variance parameters of male gymnasts classified as late, on time and early in skeletal maturation (Mean ± SD) and comparison between these groups of relative skeletal age (SA-CA).

<table>
<thead>
<tr>
<th></th>
<th>Total sample</th>
<th>Late (n=5)</th>
<th>On Time (n=17)</th>
<th>Early (n=1)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRPR_L</td>
<td>-1.8 ± 2.2</td>
<td>-2.6 ± 1.2</td>
<td>-3.0</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>DIDI_L</td>
<td>-2.6 ± 2.2</td>
<td>-3.3 ± 2.3</td>
<td>-3.0</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>PRPR_R</td>
<td>-1.8 ± 1.8</td>
<td>-3.0 ± 1.3</td>
<td>-5.0</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>DIDI_R</td>
<td>-3.0 ± 1.7</td>
<td>-3.9 ± 1.4</td>
<td>0.0</td>
<td>0.18</td>
<td></td>
</tr>
</tbody>
</table>

Kruskal-Wallis Test: p ≤ 0.05

Absolute and proportional frequency distributions within the UV categories (negative, neutral and positive) are given in Table 3.
**Table 3** - Absolute (n) and proportional (%) frequency distributions of ulnar variance (UV) categories in Portuguese skeletally immature male gymnasts.

<table>
<thead>
<tr>
<th>Group</th>
<th>PRPR-L</th>
<th></th>
<th></th>
<th>PRPR-R</th>
<th></th>
<th></th>
<th>DIDI-L</th>
<th></th>
<th></th>
<th>DIDI-R</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>±</td>
<td>+</td>
<td></td>
<td>-</td>
<td>±</td>
<td>+</td>
<td>-</td>
<td>±</td>
<td>+</td>
<td>-</td>
<td>±</td>
</tr>
<tr>
<td>Total sample (n=23)</td>
<td>n</td>
<td>17</td>
<td>6</td>
<td>0</td>
<td>18</td>
<td>5</td>
<td>0</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>73.9</td>
<td>26.1</td>
<td>0.0</td>
<td>78.3</td>
<td>21.7</td>
<td>0.0</td>
<td>87.0</td>
<td>8.7</td>
<td>4.3</td>
<td>87.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Group A (n=9)</td>
<td>n</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>55.6</td>
<td>44.4</td>
<td>0.0</td>
<td>77.8</td>
<td>22.2</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Group B (n=14)</td>
<td>n</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>85.7</td>
<td>14.3</td>
<td>0.0</td>
<td>78.6</td>
<td>21.4</td>
<td>0.0</td>
<td>78.6</td>
<td>14.3</td>
<td>7.1</td>
<td>78.6</td>
<td>21.4</td>
</tr>
</tbody>
</table>

**Chi-Square Test**
- p value = 0.11
- p value = 0.96
- p value = 0.33
- p value = 0.14

* = UV negative; ± = UV neutral; + = UV positive
For the total group of gymnasts, most of the subjects were located within the UV negative category (varying from 73.9% for PRPR-L to 87.0% for both DIDI-L and DIDI-R). The amount of gymnasts in the UV neutral category was much lower (varying from 26.1% for PRPR-L to 8.7% for DIDI-L) and only one subject demonstrated positive UV (4.3%). Although the majority of the gymnasts presented negative UV values in both age groups, the frequency of neutral PRPR in the youngest group (A) was slightly higher when compared to group B, whereas no neutral DIDI values were found in group A. When comparing PRPR and DIDI values, no significant differences could be observed between groups.

Table 4 shows the partial correlations between UV, and biological and training characteristics, controlling for CA, SA and SA-CA. When controlled for CA and SA, an inverse association between UV and Fat% (r = \(-0.45\) until \(r = -0.64\)) was observed. Analyzing DIDI-R a significant correlation with handgrip-L (r = -0.55) was found by controlling for CA, and significant correlations with stature (r = 0.46) and years of training (r = 0.47) were demonstrated by controlling for SA. Only one significant correlation was observed between UV values and biological and training characteristics when controlled for SA-CA, and that was between PRPR-L and handgrip strength in the same side (r = -0.55).
Experimental Work

Table 4 - Spearman partial correlations between ulna variance, and biological and training characteristics from Portuguese skeletally immature male gymnasts, controlling for chronological age (CA), skeletal age (SA) and difference between SA and CA (SA-CA).

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRPR-L</th>
<th>PRPR-R</th>
<th>DIDI-L</th>
<th>DIDI-R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>CA</td>
<td>SA</td>
<td>SA-CA</td>
<td>CA</td>
</tr>
<tr>
<td><strong>Biological characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass</td>
<td>0.05</td>
<td>-0.09</td>
<td>-0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>Stature</td>
<td>0.06</td>
<td>-0.06</td>
<td>-0.24</td>
<td>0.05</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.05</td>
<td>-0.14</td>
<td>-0.18</td>
<td>0.08</td>
</tr>
<tr>
<td>Fat (%)</td>
<td><strong>-0.64</strong></td>
<td><strong>-0.63</strong></td>
<td>-0.24</td>
<td>-0.33</td>
</tr>
<tr>
<td>FFM</td>
<td>0.24</td>
<td>0.05</td>
<td>-0.08</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Training characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours/week</td>
<td>-0.15</td>
<td>-0.18</td>
<td>-0.31</td>
<td>-0.30</td>
</tr>
<tr>
<td>Starting age</td>
<td>-0.07</td>
<td>-0.05</td>
<td>-0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Years of training</td>
<td>0.09</td>
<td>-0.01</td>
<td>-0.24</td>
<td>0.02</td>
</tr>
<tr>
<td>Handgrip-L</td>
<td>-0.31</td>
<td>-0.32</td>
<td><strong>-0.55</strong></td>
<td>-0.08</td>
</tr>
<tr>
<td>Handgrip-R</td>
<td>0.18</td>
<td>0.00</td>
<td>-0.40</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Ulnar variance characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PRPR-R</td>
<td>0.74*</td>
<td>0.71*</td>
<td>0.78*</td>
<td>-</td>
</tr>
<tr>
<td>DIDI-L</td>
<td>0.59*</td>
<td>0.58*</td>
<td>0.53*</td>
<td>0.61*</td>
</tr>
<tr>
<td>DIDI-R</td>
<td>0.50*</td>
<td>0.42</td>
<td>0.52*</td>
<td>0.35</td>
</tr>
</tbody>
</table>

* p ≤ 0.05
Concerning wrist pain, ten out of the twenty-three gymnasts (43.5%) reported wrist pain of gradual onset and five out of these ten evidenced bilateral pain. Six subjects (26.1%) showed pain in their right wrists (5 negative UV and 1 neutral) while 17 (73.9%) showed no pain. Nine subjects (39.1%) showed pain in their left wrists (7 negative and 2 neutral PRPR and 7 negative, 1 neutral and 1 positive DIDI) while 14 (60.9%) showed no pain. The negative PRPR values evidenced a discreet higher percentage of painful wrists in contrast to DIDI that showed higher percentage of painless wrists.

Differences in UV data between painful and painless wrists are given in Table 5.

Table 5 - Ulnar variance and handgrip strength differences between painful and painless wrists from Portuguese skeletally immature male gymnasts.

<table>
<thead>
<tr>
<th></th>
<th>Painful</th>
<th>Painless</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 (26.1)b</td>
<td>17 (73.9)b</td>
<td></td>
</tr>
<tr>
<td>Right wrist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-R (mm)</td>
<td>Mean ± SD</td>
<td>-3.2 ± 1.5</td>
<td>-2.7 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>-3.5</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>-5 / -1</td>
<td>-5 / 0</td>
</tr>
<tr>
<td>DIDI-R (mm)</td>
<td>Mean ± SD</td>
<td>-3.3 ± 2.1</td>
<td>-3.7 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>-4</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>-6 / 0</td>
<td>-6 / 0</td>
</tr>
<tr>
<td>Handgrip-R (Kg)</td>
<td>Mean ± SD</td>
<td>26.1 ± 5.5</td>
<td>20.9 ± 6.9</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>24.3</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>22.0 / 37.0</td>
<td>12.0 / 36.5</td>
</tr>
<tr>
<td>Left wrist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR-L (mm)</td>
<td>Mean ± SD</td>
<td>-2.7 ± 1.7</td>
<td>-2.3 ± 1.3</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>-5 / 0</td>
<td>-4 / 0</td>
</tr>
<tr>
<td>DIDI-L (mm)</td>
<td>Mean ± SD</td>
<td>-3.1 ± 3.1</td>
<td>-3.1 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>-4</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>-6 / +4</td>
<td>-6 / 0</td>
</tr>
<tr>
<td>Handgrip-L (Kg)</td>
<td>Mean ± SD</td>
<td>23.8 ± 8.25</td>
<td>19.9 ± 6.23</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>24.0</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>12.0 / 37.5</td>
<td>9.0 / 31.5</td>
</tr>
</tbody>
</table>

a Mann-Whitney test: * p ≤ 0.05; b n (%)  

No significant differences were observed in the UV values between painful and painless wrists, and handgrip strength values were higher in painful when compared to painless wrists. There was a statistical difference in right side handgrip strength when compared painful with painless wrists (p = 0.02).
From the group of 10 gymnasts where 15 wrists with pain were found (5 gymnasts presented both wrists with pain), 9 (60%) were classified as unrestricted (grade 1), 5 (33.3%) could attend all training sessions, but were unable to do full workout (grade 2) and only 1 (6.7%) was forced to miss one training session (grade 3).

Pommel horse was the apparatus most frequently associated with 8 of the 15 painful wrists referred by gymnasts.

4. Discussion

The Portuguese gymnasts included in our sample showed a trend to be, on average, shorter and lighter than the reference Portuguese male population of the same chronological age (Maia et al., 2007), with the particularity that the percentiles of height, weight and BMI from gymnasts evidenced a decrease with increasing age, when compared to the reference values (P 25-50 in group A, and between P10-25 in group B), which is in agreement with data from other studies involving male gymnasts (Claessens et al., 1991; Malina et al., 2004).

Despite their smaller body, Portuguese gymnasts are stronger in handgrip when compared to the reference population (Maia et al., 2007), with results within the percentiles 50-75 in group A and P25-50 in group B.

Concerning to the maturity status, most gymnasts were classified on time or average, which is in accordance by previous data on male gymnasts as demonstrated by Baxter-Jones & Maffulli (2003) and Malina et al. (2004).

UV of immature populations is on average negative as demonstrated by the data of Hafner and coworkers (1989). Our sample of Portuguese gymnasts showed also, on average, a negative UV. Despite a more negative UV than the normative values from the immature population (Hafner et al., 1989), significant differences in relation to the general population could only be found for DIDI-R (p < 0.01). The normative values presented by Hafner et al. (1989) in this age group range from -2.2 to -2.3 mm, whereby the results of PRPR (left and right) and DIDI-L from the 23 Portuguese male gymnasts (7 to 16 years) didn't show
significant differences when compared to the general population (ranging from \( p = 0.55 \) to \( p = 0.65 \)). While Chang et al. (1995) didn’t find significant differences in UV values between their sample and a control group of Chinese musicians, other studies involving gymnasts (DiFiori et al., 2002a; DiFiori et al., 1997) showed significantly less negative UV when compared with normative values from Hafner et al. (1989), which can be justified by the different conditions of the referred studies such as the different methods used to measure UV (Perpendicular and Hafner’s methods), different observers, possible differences in laterality and dominance hands, and ethnographic-related factors (Amaral et al., 2011).

The length of ulna relative to the length of the radius is not constant but varies in the course of life (De Smet, 1994). Change in UV can be attributed simply to CA, SA, SA-CA and, in the case of gymnasts, may also be eventually due to training characteristics.

In the study of Hafner et al. (1989) it was demonstrated that the UV of immature populations is on average negative and UV measures becomes somewhat more negative with increasing age. This trend was observed in PRPR from Portuguese gymnasts. The group of the older gymnasts (B) showed more percentage of negative PRPR and less neutral PRPR than the younger group (A). Oppositely, the 100% negative DIDI in group A tends to become less negative and therefore more neutral or even positive.

Some studies with gymnasts’ populations longitudinally followed during years (Claessens et al., 2003; Claessens et al., 1997) found that a negative UV (DIDI) becomes more pronounced with increasing age, while in other longitudinal studies (DiFiori et al., 2006; Dwek et al., 2009) it was demonstrated that the negative UV (PRPR) observed at baseline became significantly less negative than age-appropriate normative values. Because authors from different studies have used different UV variables (PRPR or DIDI) it is not easy to explain these divergent results and therefore this issue still remains unclear. But, following the concept of Hafner et al. (1989), gymnasts with less CA or SA or late maturing should have less negative UV when compared with the older or early maturing. Although the majority of early maturing gymnasts had presented UV values
more negatives than those at “on time” or late maturing, (see table 2), there were no significant differences between them (p = 0.12 until p = 0.53) and no significant correlation was found between UV (PRPR or DIDI) and CA. These observations are in accordance with the results from DiFiori at al. (2002a). On the contrary, Beunen et al. (1999) have verified a significant but rather low correlation (r = 0.22) between SA and PRPR, suggesting that gymnasts with more advanced skeletal age tend to show a more positive UV. In our study, when UV was controlled for maturity status no significant correlations were observed between UV measures and biological or training characteristics.

With the assumption that wrist load contributes to changes on UV, variables such as the gymnast’s weight, fat mass percentage and fat-free mass could be related with UV values, emphasizing the idea that bigger and heavier immature gymnasts have a higher risk of developing positive UV. However our findings, when controlling for CA, are in agreement with other studies on immature male gymnasts in which also no significant associations between UV and weight and stature were observed (DiFiori et al., 1997). Nevertheless, when our data were controlled for SA, the taller Portuguese gymnasts show a trend towards a positive UV - DIDI-R (r = 0.46). When our data were controlled for CA or, essentially, for SA, the gymnasts with less fat% values tend to present more positive UV, probably explained by the training over the years, which had also a significant correlation with UV (r = 0.47).

The negative correlation observed between PRPR-L (controlled for SA-CA) and left handgrip strength (r = -0.55) contradicts the results from DiFiori et al. (2002a) and suggests that the higher the handgrip strength is the less positive the UV will become.

Comparing our sample of Portuguese gymnasts with elite male gymnasts (Georgopoulos et al., 2004; Markou et al., 2004), it is demonstrated that our gymnasts train, on average, well below that of the elite level when hours/week were taken as the training variable, 17.8 vs. 27 hours/week.

Significant correlations could not be found for “hours/week” or “starting age” with the UV parameters (PRPR and DIDI), even when controlled for CA, SA or
SA-CA (see table 4), indicating no significant association between training stimulus and UV.

Several studies suggest that gymnastics training, with sufficient volume and intensity may precipitate abnormal changes of the distal radial growth plate and eventually lead to a premature physeal closure and consequent positive UV (Caine et al., 1992; Chang et al., 1995). Based on these supposed consequences, it is possible to expect a tendency towards a positive UV over the years as a result of gymnastics training. However, it is not clear if training load provokes UV changes. In most studies the authors did not find significant association between UV and training variables (Claessens et al., 1996; De Smet et al., 1994; DiFiori et al., 2002a; DiFiori et al., 1997).

Because most studies have cross-sectional designs, the association between time of exposure to training and UV changes is unclear. Some longitudinal studies obtained also contradictory results about the possible influence of gymnastics training on UV. Chang et al. (1995) and Mandelbaum et al. (1989) have observed a tendency towards a positive UV with the increase in years of training. DiFiori et al. (2002a) found a significantly higher positive UV in a group of elite when compared to nonelite collegiate gymnasts. In contrast, Claessens et al. (2003) have shown that the observed negative UV in female gymnasts at baseline became more pronounced over the years when training level increased, contradicting the results of positive UV found in the literature. For this reason, some authors consider that AG training does not have a direct negative impact in the relative position of the distal extremities of the ulna compared to the radius, resulting in an ulna’s overgrowth (Claessens et al., 2003).

In our study, the etiology of pain was of micro traumatic or gradual onset (43.5%) and the pommel horse was the apparatus most frequently related to wrist pain (53.3%), which is in accordance with the results from other research (DiFiori et al., 2002a; DiFiori et al., 1997; DiFiori et al., 1996; Mandelbaum et al., 1989).
In spite of presenting symptomatic wrists, a considerable amount of our gymnasts (60%) were able to train without limitations, which is a similar finding as demonstrated in other studies (DiFiori et al., 1996; DiFiori et al., 2002b). In fact only a few percentage has been forced to interrupt at least one training session per month, suggesting an underestimation related to the wrist pain, which may create a potential factor of morphologic alterations from distal radius or/and ulnar growth plates, changing the UV.

Based on Webb and Rettig (2008) it can be said that UV affects the distribution of forces across the wrist and the load on the neutral UV wrist is normally shared between radius and ulna in a ratio of approximately 80:20 (Anderson et al., 1998), increasing on negative UV (Bu et al., 2006), implying that wrists with greater negative UV have higher prevalence of pain (Difiori et al., 2006; DiFiori et al., 2002a; Dwek et al., 2009).

Contrary to the data gathered by DiFiori et al. (2002a), we didn’t find significant differences in the UV negative values between gymnasts with and without wrist pain.

Gymnasts with pain in the right wrist have shown more handgrip strength when compared with asymptomatic ones (p = 0.02). Contrary to the expected, the wrist pain and possible muscle-skeletally modifications didn’t reduce handgrip strength as claimed by some authors (Balogun et al., 1991). One possible explanation may be related to their biological characteristics or training programs because gymnasts more exposed to heavy training loads may be also more prone to joint overuse risk injuries and higher pain experience.

Although we have categorized objectively the gymnasts in different categories according to the dysfunction caused by wrist pain, we also need to consider that the reporting of pain by gymnasts is subjective and thus can be influenced by age, sensitivity threshold, personality and motivation.

Although our results may contribute somewhat to the generalized knowledge about the UV in gymnasts and its association with certain biological and training characteristics, the etiology of UV remains unclear. In order to evaluate the impact of gymnastics training characteristics in UV and to assess possible
contributing factors to the wrist pain, more longitudinal studies in gymnasts with control groups should be performed.

5. Limitations of this study

As limitations on this study we can consider the rather small number of subjects and the absence of a control group to evaluate the effect of training and biological characteristics in UV. Also, due to the cross-sectional design of our study a real ‘effect’ of training on UV results could not be proven, being the negative values of UV expected.

Furthermore, this study did not evaluate other more precise training characteristics such as the quantification of training load (e.g. intensity, number of elements and routines performed for each phase of the yearly training cycle, individual techniques, etc.) which may be different between gymnasts with the same number of weekly hours of training.

6. Conclusions

Portuguese skeletally immature male gymnasts present a discrepancy between chronological and skeletal ages which become more pronounced with increasing age. All average values of UV were negative and didn't present significant differences both between groups nor when compared with the reference population’s values. Although some significant results obtained in this research, such as the correlations between UV and some variables (stature, Fat%, years of training and handgrip strength), the main results do not directly support the thesis that gymnastics' training or biological characteristics present an evident association with UV. Also the association between UV values and the occurrence of wrist pain could not be demonstrated.
Fatores associados à dor no punho em ginastas portugueses

Factors associated with wrist pain in Portuguese gymnasts

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Running Head: Dor no punho em ginastas

Palavras-chave: Ginástica Artística, dor, punho, variância cubital

Keywords: Artistic Gymnastics, pain, wrist, ulnar variance

Under review: 2012, Revista Portuguesa de Ciências do Desporto
Resumo

O presente estudo pretendeu analisar os fatores determinantes na dor no punho dos ginastas portugueses, bem como detetar os grupos com maior risco. Foram observados 77 atletas de competição de Ginástica Artística (40 raparigas e 37 rapazes), com idades compreendidas entre os 7.2 e 28.4 anos. Em média, os ginastas observados treinam 18.6 horas semanais e praticam a modalidade há 8.1 anos.

Para avaliação da maturidade óssea e variância cubital foram utilizadas radiografias da mão e punho esquerdos. Uma balança analógica e um estadiómetro foram utilizados para caracterização antropométrica e a composição corporal e percentagem de gordura corporal foram obtidas pela análise da impedância bioelétrica. A força de preensão foi avaliada através de um dinamómetro mecânico e os dados referentes à dor e características do treino através de entrevista.

A dor no punho foi referenciada por 45.5% dos ginastas. A idade cronológica, escalões competitivos, horas semanais de treino, peso, estatura, %gordura corporal e força de preensão, quando analisados individualmente, foram fatores determinantes no risco de sintomatologia dolorosa, no entanto apenas a idade teve influência significativa após o seu ajuste (p=0.022 e p=0.006). Concluindo, os ginastas mais velhos têm 4.8 vezes maior propensão para dor no punho que os mais novos.
Abstract

The purpose of this study was to analyze the determinants of wrist pain in Portuguese gymnasts, as well as detecting the groups of most risk. We studied 77 athletes of Artistic Gymnastics (40 girls and 37 boys) aged between 7.2 and 28.4 years. On average, the observed gymnasts trained 18.6 hours per week and they were involved in gymnastics training since about 8.1 years.

For assessment of bone maturity and ulnar variance, radiographs from left hand and wrist were performed. An analog scale and a stadiometer were used to characterize anthropometric and body composition and percentage of body fat were obtained by bioelectrical impedance analysis. Handgrip strength was assessed using a mechanical dynamometer and data related to pain and training characteristics through interviews. The wrist pain was referred by 45.5% of gymnasts. Chronological age, competitive age-levels, hours of weekly training, weight, height, %body fat and handgrip strength, when analyzed individually, were crucial factors in the risk of painful symptoms. Nevertheless, after adjustment only chronological age had a significant influence (p=0.022 e p=0.006). In conclusion older gymnasts are 4.8 times more prone to wrist pain than younger ones.
1. Introdução

A Ginástica Artística (GA), pela sua especificidade, complexidade dos movimentos técnicos e pelo grau de habilidades que lhe é próprio, impõe aos praticantes um início de atividade desportiva precoce. Por iniciarem o treino em idades muito jovens, ainda sem fusão completa das epífises (Daly et al., 2001), a cartilagem de crescimento do punho dos ginastas torna-se um potencial local de lesões (Caine et al., 2006; DiFiori et al., 2006; DiFiori et al., 2002a), que poderão ser acompanhadas ou precedidas de sintomatologia dolorosa (Daly et al., 2001; DiFiori & Mandelbaum, 1996; Mandelbaum et al., 1989).

Na realidade, os ginastas de ambos os sexos apresentam frequentemente dor no punho (DiFiori et al., 2006; Grant-Ford et al., 2003; Markolf et al., 1990), com uma prevalência entre os 56% e 79% (DiFiori et al., 2002a; 2002b; Keller, 2009), por vezes com características de dor crónica com duração superior a 1 ano (Caine et al., 1997; DiFiori et al., 2006; DiFiori et al., 2002b).

A dor no punho parece ter implicações negativas sobre o treino, em termos de procedimentos e de planeamentos periódicos, fazendo com que os ginastas treinem abaixo das suas capacidades maximais (Kolt & Kirkby, 1999), provocando a perda de dias de treino ou uma redução do número de repetições realizadas por sessão de treino (Caine, 2003; DiFiori et al., 2006; DiFiori & Mandelbaum, 1996; DiFiori et al., 2002a; 2002b; Mandelbaum et al., 1989). Por estas razões, parece importante minimizar a ocorrência, recorrência e severidade da dor no punho dos ginastas, através do conhecimento dos fatores que possam estar na sua origem e continuidade.

Segundo alguns autores (DiFiori et al., 2002a; DiFiori et al., 1996), esta sintomatologia está associada à idade mais avançada dos ginastas, ao maior número de horas de treino semanal, ao elevado nível de treino e ao tardio início da prática.

O período de crescimento rápido, devido à fraqueza transitória da fise, também tem sido referido como fase sensível para o aparecimento da dor (Caine et al., 1992; DiFiori et al., 1996), o qual ocorre, aproximadamente, por volta dos 13.5 anos nos rapazes e 11.5 anos nas raparigas (Webb & Rettig, 2008).
Variações da morfologia óssea na articulação do punho poderão ser um fator conducente ao aparecimento de sinais e sintomas no punho (Caine et al., 1992; Schuind et al., 1992), tais como dor e alterações da epífise distal do rádio nos ginastas jovens (Caine et al., 1992; DiFiori et al., 2002a), ou da variação cubital (Caine & Nassar, 2005; DiFiori et al., 2002a; Mandelbaum et al., 1989). A variação cubital (VC) é determinada pela diferença de comprimento relativo das superfícies distais do rádio e cúbito, podendo alterar a transmissão da carga na articulação do punho (Freedman et al., 1998; Markolf et al., 1990).

A importância da VC reside na sua relação com diversas patologias (Mann et al., 1992) e possível associação com a dor no punho. Mandelbaum et al. (1989) defendem que os ginastas com dor no punho são, consistentemente, ginastas com VC positivas. Contrariamente, alguns autores defendem a existência de maior tendência para a dor nos punhos com VC negativa (Amaral, Claessens, Ferreirinha & Santos, 2012b; Caine & Nassar, 2005; DiFiori et al., 2002a), enquanto outros não consideram a VC como fator determinante na dor (Chang et al., 1995; DiFiori et al., 1997).

Outros fatores que podem predispor o ginasta à dor no punho incluem a utilização de equipamento impróprio, técnicas de execução incorretas, a existência de lesões anteriores e o atraso na maturação óssea (Caine et al., 1992; DiFiori et al., 1996).

Os elementos técnicos executados nos diversos aparelhos de GA submetem a articulação do punho a recorrentes cargas com forças estáticas e dinâmicas de grande impacto (Davidson, Mahar, Chalmers & Wilson, 2005), cujas significativas duração, frequência e intensidade podem originar dor no punho nos ginastas (Davidson et al., 2005; Mandelbaum et al., 1989). Vários autores preconizam que a dor no punho e a hipersensibilidade da físe no ginasta devem ter uma avaliação radiológica imediata e acompanhamento bianual para detetar irregularidades ou alterações das físes do rádio e cúbito, efetuando um diagnóstico rápido, preciso e precoce (Caine et al., 1992; Cornwall, 2010; Daly et al., 2001; Webb & Rettig, 2008). Continua por esclarecer até que ponto um punho sintomático evoluirá para lesão a longo prazo e que medidas preventivas se justificam delinear, sejam alterações no treino em período específico do
crescimento, ou outras compensações (fortalecer, flexibilizar ou limitar amplitudes extremas através de ortóteses).

Para que a prevenção seja um aspeto importante do regime de treino do ginasta, são necessárias evidências que relacionem o aparecimento de sintomatologia dolorosa no punho do ginasta, como certas especificidades do treino desportivo, um determinado perfil biológico ou tipo de VC.

Assim, este estudo pretende avaliar a dor no punho dos ginastas portugueses de competição de Ginástica Artística e a sua relação com um conjunto de características biológicas (sexo, idade cronológica, maturidade, altura, peso, % de gordura corporal, força e variância cubital) e de treino (horas semanais e anos de prática). Pretendemos ainda identificar e quantificar os fatores de risco para o aparecimento da dor no punho dos ginastas, bem como detetar os grupos com maior predisposição.

2. Metodologia

2.1. Amostra

O grupo de ginastas em estudo é constituído por 77 atletas com idades compreendidas entre os 7.2 e 28.4 anos (média de 13.6 ± 5.0), todos filiados na Federação de Ginástica de Portugal (FGP). Estes ginastas treinam em média 18.6 ± 4.5 horas semanais e iniciaram a sua atividade aos 5.8 ± 1.7 anos de idade, com uma média de anos de prática de 8.1 ± 4.9 anos.

Da totalidade dos ginastas observados, 40 eram raparigas com idades compreendidas entre 7.2 e 18.3 anos (média de 12.14 ± 3.07 anos) e 37 eram rapazes entre os 7.2 e 28.4 anos de idade (média de 15.25 ± 6.13 anos).

Enquanto características maturacionais dos indivíduos avaliados, 56 (72.7%) dos ginastas eram imaturos, ou sem fusão óssea completa (33 femininos e 23 masculinos) e 21 (27.3%) maturos, ou com fusão óssea completa (7 femininos e 14 masculinos).
Tabela 1- Caracterização biológica da amostra: 77 ginastas (56 imaturos e 21 maturos).

<table>
<thead>
<tr>
<th>Características biológicas</th>
<th>n</th>
<th>Média (desvio-padrão)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idade cronológica - total (anos)</td>
<td>77</td>
<td>13.6 (5.0)</td>
</tr>
<tr>
<td>Idade cronológica - maturos (anos)</td>
<td>21</td>
<td>20.4 (4.0)</td>
</tr>
<tr>
<td>Idade cronológica - imaturos (anos)</td>
<td>56</td>
<td>11.1 (2.3)</td>
</tr>
<tr>
<td>Idade óssea - imaturos (anos)</td>
<td>56</td>
<td>10.4 (2.1)</td>
</tr>
<tr>
<td>IO-IC (anos)</td>
<td>56</td>
<td>-0.9 (1.1)</td>
</tr>
<tr>
<td>Peso (Kg)</td>
<td>77</td>
<td>42.0 (14.4)</td>
</tr>
<tr>
<td>Estatura (cm)</td>
<td>77</td>
<td>146.9 (14.6)</td>
</tr>
<tr>
<td>% Gordura</td>
<td>77</td>
<td>16.6 (6.8)</td>
</tr>
<tr>
<td>Força de preensão (Kg)</td>
<td>77</td>
<td>25.8 (12.4)</td>
</tr>
<tr>
<td>Variância cubital-Imaturos- PRPR (mm)</td>
<td>56</td>
<td>-2.00 (1.79)</td>
</tr>
<tr>
<td>Variância cubital -Maturos - VC (mm)</td>
<td>21</td>
<td>-0.10 (1.48)</td>
</tr>
</tbody>
</table>

De acordo com a “Declaração de Helsínquia” da associação Médica Mundial, foi obtido o consentimento informado dos ginastas de maior idade e de todos os pais dos ginastas menores participantes no presente estudo, tendo sido igualmente solicitada a autorização dos respetivos treinadores.

2.2. Variáveis e Procedimentos

2.2.1. Caracterização antropométrica e composição corporal

Para caracterização antropométrica, avaliou-se o peso utilizando uma balança analógica (Tanita – Body Fat Monitor/Scale BF-574 com acuidade de 0.1Kg) e a estatura, através de um estadiómetro (Seca Mod 220 com acuidade de 1mm). A composição corporal e percentagem de gordura corporal (%Gc) foram obtidas pela análise da impedância bioelétrica, através do procedimento descrito por Heyward e Wagner (2004).

2.2.2. Maturidade óssea

Foram utilizadas radiografias da mão e punho esquerdos para avaliação das idades ósseas, segundo o método Tanner-Whitehouse 3 - TW3, seguindo a escala de avaliação RUS (‘radius, ulnar, short bone’) (Tanner et al., 2001).
A classificação de maturidade (avançada, na média ou no tempo, e atrasada) foi definida pela idade óssea relativa avaliada pela diferença da idade óssea (IO) e a idade cronológica (IC) (IO-IC), de acordo com o conceito de Malina et al. (2006) e Baxter-Jones et al. (2003).

2.2.3. Determinação da variância cubital

Pelo facto de não haver fusão óssea completa nos jovens imaturos, as técnicas de medição da VC devem ser diferentes das que se aplicam nos adultos (maturos), requerendo critérios e métodos específicos (De Smet et al., 1994; Hafner et al., 1989; Palmer et al., 1982).

Na avaliação imagiológica do punho esquerdo, e para calcular a VC nos ginastas imaturos, foi medida a distância do ponto mais proximal da metáfise do cúbito ao ponto mais proximal da metáfise do rádio – PRPR (Claessens et al., 1996).

Para a medição da VC nos ginastas maturos foi utilizado o método de Palmer et al. (1982), utilizando semicírculos concêntricos com um raio entre 20 a 50 mm, desenhados numa película transparente, e colocada num negatoscópio. É escolhida a curva que seja mais sobreponível com a concavidade distal da linha esclerótica do rádio e colocado sobre o seu contorno, sendo a VC medida entre esta linha e a linha que intercede a extremidade do cúbito (Palmer et al., 1982).

A VC é considerada positiva quando o comprimento da extremidade distal do cúbito excede 1mm o comprimento da extremidade distal do rádio; quando o comprimento da extremidade distal do cúbito for menor do que a do rádio 1mm, a VC é negativa, e se esta distância for inferior a 1mm, a VC é definida como neutra (Hafner et al., 1989; Palmer et al., 1982).

Para avaliar a fiabilidade intra-observador das medições, foram observadas 15 radiografias de ginastas imaturos e 8 de ginastas maturos, numa prova cega em dois momentos distintos, tendo sido observadas correlações fortes (R = 0.987, 95% CI = 0.962 a 0.996 para PRPR nos imaturos, e R = 0.970, 95% CI = 0.863 a 0.994 para VC nos maturos.
2.2.4. Força de preensão

A força isométrica máxima de preensão foi avaliada através de um dinamômetro mecânico (Takei KiKi Kogyo – TK 1201, Niigata City, Japan) com acuidade de 0.5Kg, o qual foi ajustado à dimensão das mãos de cada ginasta para uma melhor performance (Schlüssel et al., 2008). Os ginastas foram instruídos para pressionar o dinamômetro ao máximo durante 5 segundos em três tentativas e com intervalos de 2 a 5 minutos para evitar a fadiga, tendo sido utilizado o valor máximo para representar a força de preensão (Balogun et al., 1991; Schlüssel et al., 2008). As avaliações foram efetuadas pelo mesmo avaliador.

2.2.5. Dados sobre o treino e dor no punho

Os dados relativos à idade de início da prática, ao número de horas semanais de treino e aos anos de prática foram obtidos através de entrevista, a qual serviu também para registo da ocorrência de sintomatologia dolorosa nos punhos dos ginastas.

2.3. Análise dos dados

Os ginastas foram agrupados em categorias com igualdade de proporções, segundo a divisão por tercis. Para caracterização da amostra utilizou-se a estatística descritiva (média, desvio padrão, frequências e percentagem de ocorrência). Com o objetivo de testar a influência das variáveis biológicas, força, variância cubital e de caraterísticas de treino no ter ou não ter dor recorreu-se à utilização da regressão logística. Inicialmente foi analisado o efeito principal de cada uma das variáveis independentes na explicação da variável dependente (ter ou não ter dor), e depois calculado o ajuste entre todas as variáveis que se revelaram estatisticamente significativas. Foi realizado o coeficiente de correlação intra classes para testar a fiabilidade intra-observador na avaliação da VC. Para efeitos da interpretação dos resultados, assumiu-se o nível de significância de 95%, ou seja, o valor de p ≤ 0.05.
3. Resultados

A incidência de dor nos ginastas imaturos e maturos foi similar (p = 0.080). A média dos ginastas imaturos foi classificada como pertencendo a um estádio maturacional considerado ‘na média’ ou ‘no tempo’ (IO-IC= -0.5 ± 1.2 anos). Na totalidade dos ginastas, as diferentes classes maturacionais (IO-IC inferior a 0.0; entre 0.0 e 1.0 e superior a 1.0) não foram fatores decisivos para o aparecimento da dor (p=0.999 e p=0.373).

O risco de ocorrência de dor foi idêntico em ambos os géneros (p=0.057) e nas diferentes categorias de VC (negativa, neutra e positiva) (p = 0.316 e 0.107).

Pela análise da tabela 2, verifica-se que a idade cronológica, o escalão competitivo, as horas semanais de treino, os anos de prática de ginástica, o peso corporal, a estatura, a percentagem de gordura e a força de preensão são determinantes significativos da dor no punho.

Tabela 2 – Modelo de regressão logística com variáveis biológicas e de treino.

<table>
<thead>
<tr>
<th>Variável Exploratória</th>
<th>N (%)</th>
<th>N (%) com dor</th>
<th>Bruto</th>
<th>Valor de prova</th>
<th>Ajustado</th>
<th>Valor de prova</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idade cronológica</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferior a 10.5</td>
<td>25 (32.5)</td>
<td>5 (14.3)</td>
<td>1</td>
<td>0.029</td>
<td>4.8 (1.3-18.4)</td>
<td>0.022</td>
</tr>
<tr>
<td>Entre 10.5 e 14.7</td>
<td>26 (33.8)</td>
<td>13 (37.1)</td>
<td>4.0 (1.2 – 13.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior a 14.7</td>
<td>26 (33.8)</td>
<td>17 (48.6)</td>
<td>7.6 (2.1 – 27.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Maturação</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaturo(^b)</td>
<td>56 (72.7)</td>
<td>22 (62.9)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturo</td>
<td>21 (27.3)</td>
<td>13 (37.1)</td>
<td>2.5 (0.9 - 7.0)</td>
<td>0.080</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Género</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feminino(^b)</td>
<td>40 (51.9)</td>
<td>14 (40)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masculino</td>
<td>37 (48.1)</td>
<td>21 (60)</td>
<td>2.4 (1.0 - 6.1)</td>
<td>0.057</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Peso</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferior a 33.6(^b)</td>
<td>42 (54.5)</td>
<td>7 (20)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entre 33.6 a 46.4</td>
<td>30 (39.0)</td>
<td>14 (40)</td>
<td>3.2 (1.0 – 10.1)</td>
<td>0.051</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior a 46.4</td>
<td>5 (6.5)</td>
<td>14 (40)</td>
<td>3.5 (1.1 – 11.2)</td>
<td>0.038</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estatura</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferior a 137.0(^c)</td>
<td>26 (33.8)</td>
<td>6 (17.1)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entre 137.0 a 154.3</td>
<td>26 (33.8)</td>
<td>13 (37.1)</td>
<td>3.3 (1.0 – 11.0)</td>
<td>0.048</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior a 154.3</td>
<td>25 (32.5)</td>
<td>16 (45.7)</td>
<td>5.9 (1.7 – 20.2)</td>
<td>0.004</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ginastas com idade superior a 10 anos têm uma maior propensão para terem dor no punho relativamente aos ginastas com idade inferior a 10 anos (OR=4.0;
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95%CI: 1.2-13.9 e OR=7.6; 95%CI 2.1-27, respetivamente, no grupo etário dos 10-15 e no grupo ≥15 anos).

Praticantes com peso e estatura superior a 33.6kg e 137cm, respetivamente, têm mais propensão (entre 3 a 6 vezes) para ter dor no punho comparativamente a ginastas com peso e estatura inferiores. Ginastas com percentagens de gordura entre 14.7-19.0% e superior a 19.0%, são menos suscetíveis a ter dor no punho comparativamente a ginastas com uma massa gorda inferior a 14.7%.

Ginastas com força de preensão superior a 30.1Kg têm 4 vezes mais tendência para apresentar dor, quando comparados com ginastas com força inferior a 18.8Kg. Não se registaram diferenças significativas na dor entre ginastas com força de preensão inferior a 18.8 Kg e os que possuem entre 18.8 e 30.1Kg (OR: 2.6; 95%CI: 0.8-8.2).

Pode-se observar na tabela 2 que os ginastas que competem no escalão de juniores e seniores têm aproximadamente 7 vezes mais propensão para terem dor no punho relativamente aos praticantes do escalão de infantis.

Ginastas com mais de 9 anos de prática e com uma participação semanal entre 15 a 21h de treino de ginástica têm cerca de 5 vezes mais propensão para terem dor no punho, comparativamente a ginastas com menos de 6 anos de prática e com treino semanal inferior a 15 horas. Não se registaram diferenças significativas na dor do punho entre ginastas com menos de 6 anos de prática e aqueles que possuem 6-9 anos de prática (OR: 2.1; 95%CI: 0.7-6.5), bem como entre aqueles que treinam menos de 15h semanais e os que treinam mais de 21h (OR: 2.0; 95%CI: 0.4-10.9).

O efeito principal das variáveis analisadas que manifestaram dor no punho mostrou-se significativo para idade, peso, estatura, % gordura, força de preensão, nível desportivo, horas e anos de prática. No entanto, quando se ajustam todas as variáveis determinantes da dor no punho, anteriormente referidas, apenas a idade permanece como um preditor da dor. Este facto verifica-se tanto para o grupo com idade entre 10.5 e 14.7 anos (OR:4.8; 95%CI:1.3-18.4) como para o grupo dos mais velhos (OR:6.0; 95%CI:1.7-21.9).
4. Discussão

Apesar da dor no punho, de origem microtraumática, ser muito frequente nos ginastas de ambos os sexos (De Smet et al., 1993; DiFiori et al., 2006), na amostra do presente estudo não foi observada uma maioria de ginastas com sintomatologia dolorosa (45.5%), contrastando com outros estudos que obtiveram valores maioritários (DiFiori et al., 2002a; 2002b; DiFiori et al., 1996; Mandelbaum et al., 1989). Esta maior incidência dolorosa poderá ter uma causa multifatorial e, entre os vários factores, a VC tem sido referida como uma das causas predisponentes da dor e/ou de determinadas patologias.

No que diz respeito a esta variável, os ginastas portugueses imaturos apresentaram maioritariamente uma VC negativa (-2.00mm), o que é coincidente com os dados da literatura relativos tanto à população de referência para indivíduos imaturos (Hafner et al., 1989; Webb & Rettig, 2008), como para ginastas também imaturos (Amaral et al., 2012a; 2012b; Claessens et al., 2003; Claessens et al., 1997; Claessens et al., 1998; DiFiori et al., 2002a; DiFiori et al., 1997; Dwek et al., 2009). Os ginastas portugueses maturos (fusão óssea completa) apresentaram uma VC neutra (-0.10mm).

Partindo do prossuposto que a diferença de comprimento ósseo é determinante na área onde se exerce maior pressão (na VC negativa existe um maior desequilíbrio na distribuição de carga entre o rádio e o cubito, 94:6) (Bu et al., 2006), os ginastas imaturos com VC negativa teriam assim maior probabilidade de sofrer alterações morfológicas na extremidade distal do rádio (Caine & Nassar, 2005; DiFiori et al., 2002a) e, presumivelmente, apresentar maior prevalência de dor (Caine et al., 1992; DiFiori et al., 2002a; Gerbino, 1998). Porém, não foram encontradas diferentes predisposições ao aparecimento de dor no punho dos ginastas portugueses nas diversas categorias de VC (negativa, neutra e positiva), resultados que são coincidentes com os de outros estudos (Chang et al., 1995; DiFiori et al., 2002a; DiFiori et al., 1997).

Também a maturidade e os diferentes estádios maturacionais dos ginastas portugueses parecem não interferir no aparecimento de dor, o que contraria a opinião de vários autores (Caine et al., 1992; Cornwall, 2010; De Smet et al., 1993; Kerssemakers et al., 2009; Zetaruk, 2000) que defendem a imaturidade e
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o atraso na maturação óssea como fatores de vulnerabilidade óssea, provavelmente pelo prolongar do tempo de exposição do sistema músculo-esquelético imaturo a stresses biomecânicos repetidos, possíveis causadores de dor. De acordo com este conceito, seria de esperar uma maior frequência de dor nos ginastas imaturos relativamente aos maturos, no entanto isso apenas se verificou percentualmente (62.9% vs. 37.1%), não tendo sido encontrado qualquer significado estatístico (p = 0.080). Portanto, os nossos dados sugerem que a dor não será uma consequência da VC, nem do estádio maturacional dos ginastas.

Na presente investigação constatámos a existência de diferentes variáveis (intrínsecas e extrínsecas) preditivas da dor no punho, mas apenas quando analisadas isoladamente. De facto, quando analisadas em conjunto, apenas a idade permanece como um preditor da dor, tanto para o grupo com idade entre 10.5 e 14.7 anos (p= 0.022) como para o grupo dos mais velhos (p= 0.006). Assim, mediante as variáveis biológicas e de treino utilizadas neste estudo, os resultados indicam que ser mais velho, por si só, aumenta significativamente o risco de ter dor no punho. Contudo, convirá referir que existem outras variáveis, nomeadamente indicadores de carga/impacto dos diversos exercícios de apoio realizados pelos ginastas, que não foram qualificados e quantificados, e que, eventualmente, poderiam ser fatores indutores de dor no punho dos ginastas. Outra possível justificação será o facto de a idade estar, em parte, diretamente relacionada com outras variáveis analisadas, como os anos de prática que implicitamente incluem fatores de treino e biológicos, causadores de sobrecarga e sobreuso na articulação do punho.

Com o objetivo de determinar grupos de maior risco e analisando isoladamente as características biológicas dos ginastas portugueses de competição, representativos da GA da FGP, verificamos que a idade cronológica, o peso, a estatura, %gordura e força de preensão estão relacionados com a incidência de dor no punho. Como acima referido, a idade cronológica é uma das variáveis significativamente associada à dor no punho, tal como observado por DiFiori et al. (2002b) e DiFiori et al. (1996). A frequência da dor e o risco do seu aparecimento aumenta proporcionalmente com a idade dos ginastas, como
defendido por diversos autores (Claessens, 2004; DiFiori et al., 2002a; 2002b; DiFiori et al., 1996). No entanto, os ginastas portugueses apresentam percentagens de presença de dor de 14.4%, 37.1% e 48.6%, por intervalo de idades, inferiores aos valores de diversos estudos com ginastas (DiFiori et al., 2002a; 2002b; Mandelbaum et al., 1989), possivelmente pelas diferentes metodologias utilizadas, quer no treino, quer na avaliação, ou pelas diferenças biológicas características de cada grupo amostral.

A especificidade dos gestos técnicos da GA transformam o punho numa articulação de apoio/carga e de suspensão, o que poderá explicar parcialmente a razão pela qual os ginastas mais pesados, do presente e de outros estudos (DiFiori et al., 2002a; DiFiori et al., 1996), são mais suscetíveis ao aparecimento de dor, como resultado das altas forças que o sistema músculo-esquelético fica submetido (Emery, 2003). De forma similar e em concordância com os resultados de DiFiori et al. (2002a; 2002b), os ginastas de maior estatura evidenciaram maior probabilidade de terem punhos com sintomatologia dolorosa.

Se partilharmos o conceito simplista de que o índice peso/altura pode ser usado como indicador de %G ou que um aumento de %G está usualmente associado a um aumento do peso corporal, conforme referiu Deurenberg, Deurenberg-Yap & Guricci (2002), seria de esperar uma relação diretamente proporcional no risco do aparecimento da dor. Porém, surpreendentemente, verificou-se uma associação significativa e inversamente proporcional entre a dor e a percentagem de gordura nos ginastas observados, ou seja, os que apresentaram menor %G evidenciaram maior risco de ter dor. Podemos admitir, apesar de não poder comprovar, que os valores mais baixos de %G possam estar associados aos ginastas com maior número de horas de treino, mais anos de prática, maiores níveis de força, portanto mais velhos e, consequentemente, com maior risco de ter dor.

Outro fator determinante na presença de dor no punho foi a força de preensão, frequentemente utilizada como um indicador geral da totalidade de força muscular, por estar fortemente correlacionada com a força muscular total e a performance física (Balogun et al., 1991; De Smet & Vercammen, 2001; Häger-
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Ross & Rösblad, 2002; Wind, Takken, Helders & Engelbert, 2009). No entanto, somente os ginastas com força de preensão superior a 30.1Kg apresentaram um maior risco de dor em relação aos outros ginastas. O risco de ter dor nos outros dois grupos foi igual, contrariamente ao expetável, visto que a redução/inibição da força pode ser explicativa de alterações músculo-esqueléticas (Balogun et al., 1991; Häger-Ross & Rösblad, 2002). Por outro lado, também era esperado que os atletas com maior força tivessem menor probabilidade de ter dor - pela possível proteção dada pelas estruturas musculares às estruturas ligamentares e ósseas, proporcionando-lhes maior estabilidade e controlo articular - o que não se verificou. Além da referida proteção, os músculos podem atuar como fatores de risco, pela criação de forças compressivas ou de tensão, aplicadas às estruturas ósseas. No entanto, DiFiori et al. (2002a) consideram não existirem diferenças significativas entre a força de preensão e a presença de dor, tanto nos valores absolutos da força, como quando ajustados para o peso.

Supostamente, a dor no punho do ginasta pode dever-se à carga de treino a que o ginasta está sujeito, usualmente quantificada pelo número de h/sem despendidas na prática desportiva (Caine, 2003). Os nossos resultados permitem-nos afirmar que existe um limiar de risco (entre 15 e 21 h/sem), ao contrário de algumas referências na literatura que associam a frequência da dor ao número de horas de treino dos ginastas (Claessens, 2004; DiFiori et al., 2002a; DiFiori et al., 1996; Mandelbaum et al., 1989), pelo tempo de exposição ao risco lesivo/sobreuso.

Outros autores (DiFiori et al., 1996; Mandelbaum et al., 1989) referem ainda que os impactos compressivos de repetição e duração significativa, a frequência e intensidade do treino, o progressivo crescimento do risco e a complexidade/dificuldade das rotinas executadas poderão ser causas para a ocorrência de sintomatologia dolorosa.

Quanto à relação entre o tempo de prática e a dor no punho, o risco de ter dor surge apenas após os 9 anos de prática. Os resultados encontrados na literatura (DiFiori et al., 2002a; DiFiori et al., 1996) não são comparáveis com os do presente estudo, pela média de anos de prática ser inferior à dos
ginastas portugueses (entre 3.3 ± 2.2 e 5.4 ± 2.4 anos), estando todos incluídos no 1º tercil, considerado como padrão. Apesar desta média de anos de prática ser muito inferior ao tempo de prática considerado como risco nos ginastas portugueses, Difiori et al. (2002a) observaram diferenças significativas entre os ginastas com e sem dor, quando analisados os anos de prática.

Uma vez que no intervalo de idades entre 10.5 e 14.7 anos já há uma probabilidade 4 vezes maior de ocorrer dor, pensamos que se justifica atuar antes dessa idade. Embora os resultados, após o ajuste de todas as variáveis significativas, demonstrem que a única variável preditora de dor é a idade, também verificámos que, aquando da análise individual, existem variáveis que contribuem, em parte, para o aparecimento da dor. Portanto, julgamos importante controlar as variáveis que se mostraram determinantes na dor do punho, tais como peso e % gordura, procurando ainda vigiar com especial atenção os ginastas com maior estatura, com maior força de preensão e com maior volume de treino (entre 15 a 21h semanais).

5. Conclusões

A dor no punho é comum nos ginastas, sendo que a idade parece ser o único fator determinante no risco de aparecimento da sintomatologia dolorosa nesta articulação, com os atletas mais velhos a apresentarem uma maior probabilidade de ter dor no punho.

Parece-nos pertinente uma intervenção precoce a nível da prevenção primária do aparecimento da dor, durante a fase de imaturidade, com idades inferiores a 10 anos, contribuindo para redução da incidência e/ou prevalência dos sintomas dolorosos nas idades mais avançadas, em que o risco aumentou significativamente.

Não foram observadas relações causais entre a dor no punho e as diferentes categorias de VC, ou seja, a diferença de comprimento do rádio e do cúbito não representou um fator de risco de dor no punho, embora se tenha verificado menor frequência de dor nos punhos com VC positiva.
6. Limitações

Sendo um estudo com desenho transversal, a determinação causa-efeito do treino, das características biológicas e da variância cubital na ocorrência de dor no punho não puderam ser confirmadas. A subjetividade da dor e a heterogeneidade das idades dos ginastas podem dificultar a quantificação e valorização dos sintomas dolorosos.

Embora a amostra seja representativa dos ginastas portugueses de competição de GA, quando subdividida em tercis, reduz substancialmente o número de atletas em cada grupo, o que poderá limitar a análise estatística.
Experimental Work

Does age and training affect ulnar variance?

Study IV

Experimental article


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Running head: Does age and training affect Ulnar Variance?

Keywords: Immature Gymnasts; wrist; ulnar variance; age; training

Publication status: 2012, not submitted
Abstract

The purpose of this study was to investigate the variability and changes of ulnar variance in a group of 25 Portuguese’s immature artistic gymnasts (aged 10.40 ± 1.74 yr) followed during 18 months.

Left ulnar variance was obtained using Hafner’s procedure and skeletal age was determined by the Tanner-Whitehouse 3-method, and radius, ulna, and short bone system. At baseline was observed a negative mean value of ulnar variance (-3.48 to -2.48mm). Gymnasts showed significant ulnar variance changes between the 1st and the 2nd moment (p ≤ 0.001), becoming more positive (-1.46 to -0.12mm). This change was not uniform nor in the individual patterns, nor in the frequency of ulnar variance’s categories.

Using ANCOVA controlling for chronological age, a significant interaction was found between age and time effect in ulnar variance at baseline (p = 0.025 to PRPR and p = 0.014 to DIDI).

In conclusion, in immature gymnasts, age seems not to be the only factor for a specific UV changes during a period of 18 months. Different UV categories react differently to a period of time with training.

There were relationships between same biological and training variables with ulnar variance for each moment and for ulnar variance changes.
1. Introduction

In Artistic Gymnastics, the upper extremities are often used as weight-bearing limbs (Claessens et al., 1997; Gabel, 1998; Claessens et al., 2003; Webb & Rettig, 2008; Caine et al., 1992; Hecht, 2006), with biomechanical stresses placed on the skeleton, especially on the growing ends of the radius and ulna (Dwek et al., 2009). The wrist is exposed to many different types of stress, including repetitive movements, high impact loads (DiFiori et al., 2002a), hyperextensions, axial compressions and torsional forces and distractions in various degrees of ulnar or radial deviation (DiFiori et al., 1996; Gabel, 1998, Hecht, 2006; Webb & Rettig, 2008). Indeed, the wrist excessively and repetitively loaded is particularly vulnerable to injury (Caine et al., 1992; Claessens et al., 2003) and may be the cause of abnormal changes in the distal growth plate (Caine et al., 1992; Mandelbaum et al., 1989) or wrist pain, which is a major problem in adolescent gymnasts (Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2002a).

Ulnar variance (UV) refers to the length differences between the distal articular surfaces of the radius and ulna (De Smet, 1994; Schuurman et al., 2001; DiFiori and Mandelbaum, 1996; Webb & Rettig, 2008) which affects the forces distribution across the wrist (Yoshioka et al., 2007; Webb & Rettig, 2008). According to Mann et al. (1992), the causal relationships between load and UV are attributed to anatomic and biomechanical differences among individuals with differing UV.

Some experimental studies suggest that the load on the neutral UV wrist is normally shared between radius and ulna in a ratio of approximately 80:20 (Anderson et al., 1998) and that this ratio changes with increasing or decreasing UV values: e.g. on the positive UV wrist ratio is 69:31 while on the negative UV the ratio is 94:6 (Bu et al., 2006).

As a general rule, youngsters, in terms of their biological maturation, present mostly negative UV (Hafner et al., 1989), as well as immature gymnasts (Claessens et al., 1997; DiFiori et al., 1997; Claessens et al., 1998; DiFiori et al., 2002a; Claessens et al., 2003; Amaral et al., 2012a; 2012b), which can induce a significant overload across the radius in skeletally immature gymnasts (DiFiori et al., 2002a; DiFiori et al., 2006; Webb & Rettig, 2008).
However, there are several reports showing the prevalence of relative and absolute positive UV in gymnasts, when compared to skeletally mature control groups (Mandelbaum et al., 1989; De Smet et al., 1994; Chang et al., 1995) and immature non-athlete population (DiFiori et al., 1997; DiFiori et al., 2002a; Dwek et al., 2009). The gymnasts’ trend to a positive UV is often explained by the chronic injury of the distal radial physis (Chang et al., 1995; De Smet et al., 1994; Mandelbaum et al., 1989; Dwek et al., 2009). Some authors claim that repetitive injury of the radial epiphysis may inhibit the normal growth of the radius resulting in a positive UV (Roy et al., 1985; Caine et al., 1992; De Smet et al., 1994).

The length of the ulna relative to the radius (expressed by UV) varies in the course of life (De Smet, 1994), and has been reported that factors such as age (Claessens et al., 1997; Dwek et al., 2009) and/or training may affect the UV (Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2002a).

Based on the available evidence from several clusters of results it is possible to observe a lack of consensus.

Evaluated cross-sectional studies, seeking an association between age and UV, several authors claim that changes in relative ulna’s length in immature gymnasts were not significantly related with chronological age (De Smet et al. 1994, Claessens et al., 1996; DiFiori et al., 1997; DiFiori et al., 2002a; Amaral et al., 2012a; 2012b). Regarding longitudinal studies, some authors found a relatively stable pattern of negative UV throughout the growth period, concluding that negative UV (DIDI) in immature female gymnasts becomes more pronounced with increasing age (Claessens et al., 1997; Claessens et al., 2003). On the other hand, Dwek et al. (2009) observed a significant trend from negative UV (PRPR) to more positive with advancing age. In mature reference population the UV does not change significantly during adult life (Chen & Wang, 2008).

In most studies, especially case-reports, the authors suggest a dose-response relationship between training characteristics and UV (Claessens, 2001; Claessens, 2004). Based on the literature is possible to observe different results and does not appear to be consensus on this matter. Some authors state a
tendency toward positive UV, that is, the higher gymnasts’ training and/or competition level more pronounced is the positive UV observed (Mandelbaum et al., 1989; Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2002a; Roy et al., 1985). Others claim that the negative UV observed at the beginning became more pronounced over the years with increased training level (Claessens et al., 1997; Claessens et al., 2003). There are also authors who did not find any significant association between training characteristics and UV (De Smet, 1994; Claessens et al., 1996; DiFiori et al., 1997; Claessens, 2001; Claessens, 2004). So the real influence of gymnastics training on the UV phenomenon is not known.

The absence of a consensus in relation to the factors that influence UV as well as its changes across age, raises some questions. Consequently, the purpose of the present study was to investigate the variability and changes of UV in Portuguese’s immature artistic gymnasts followed during a period of 18 months:

i) to observe how UV evolves with age and training characteristics;

ii) to understand if different UV categories (positive, neutral or negative) react differently to training characteristics;

iii) to evaluate the relationship between UV and some biological or training characteristics.
2. Methods

2.1. Subjects

The sample consisted of 25 Portuguese skeletally immature gymnasts, 16 female and 9 male, all tested twice, once at baseline (September 2009) and after 18 months.

At baseline the chronological age varied between 7.2 and 14.1 years (10.4 ± 1.74 yrs). All gymnasts competed at national level, according to the Portuguese Gymnastics Federation (FGP). All subjects were recruited from several clubs located around Porto and Lisbon, the two major Portuguese cities.

The Ethical Committee of the Faculty of Sport Sciences from the University of Porto approved this protocol and an informed consent was obtained from all gymnasts or gymnasts’ parents/legal guardians in agreement with the International Medical Association Declaration of Helsinki. All gymnasts’ personal coaches were informed and their personal authorization was given.

2.2. Variables and measuring procedures

2.2.1. Chronologic and Skeletal ages

Chronological age was based on the age-table as set by Weiner & Lourie (1969). Skeletal ages were estimated based on Tanner-Whitehouse 3 method, with the radius, ulna, and short (RUS) bone system (Tanner et al., 2001). All radiographs were taken according to the standard procedures as described by Tanner et al. (2001). SA assessment was made by an orthopedist with experience in the TW3- method. To assess intra-observer reliability 15 wrists were measured twice and the ANOVA-based intra-class correlation coefficient was very high (R=0.99, 95% CI = 0.99 to 1.00).

2.2.2. Ulnar variance determination

Measuring UV was done on the same radiographs upon which skeletal maturity was assessed. Because hand and wrist position for skeletal maturity assessment is the same as for UV determination, the use of the same radiographs for both purposes is justified.
UV parameters (DIDI and PRPR) from the left hand were measured according to the method as outlined by Hafner et al. (1989) in two moments (PRPR\textsubscript{1st} and PRPR\textsubscript{2nd}, DIDI\textsubscript{1st} and DIDI\textsubscript{2nd}). PRPR is the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis; whereas DIDI is the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis. RX-plates were placed on a negatoscope and UV measurements were taken by means of a transparent plastic template marked with parallel lines 1 mm apart with an amplitude range of 0 to 50 mm.

Positive UV means that the respective ulna points are more distally located relative to the respective radius points (ulnar overgrowth), while negative UV indicates the opposite.

All measurements were taken by the same observer (LA). To assess intra-observer reliability 15 X-rays were marked and measured twice in a blind fashion. Reading’s reliability was estimated with the ANOVA-based intraclass
correlation coefficient (R) and their corresponding 95% confidence intervals: DIDI, R = 0.971, 95%CI=0.912 to 0.991; PRPR, R= 0.987, 95%CI=0.962 to 0.996).

2.2.3. Anthropometry and body composition

Stature was measured with a Seca 202 stadiometer with 1 mm accuracy. Body mass was obtained with a scale (Seca) accurate to 0.1 kg. Measurements were taken by the same experienced observer following Claessens et al. (2008) procedures. Body mass index (BMI) was calculated as body mass divided by stature (kg/m²).

Body composition components fat-free mass (FFM, kg) and percentage of body fat mass (% Fat) were obtained by means of bio-electrical impedance analysis using the Body Composition Analyzer Tanita (Type BC-418 MA). This device takes into account chronological age and sex of the subjects and the guidelines suggest categorizing individuals into two activity levels: standard and athlete (Volgyi et al., 2008). All our gymnasts were classified as standard because according to those guidelines only individuals older than 17 years can be categorized as athletes.

2.2.4. Handgrip strength

Handgrip strength was measured using a mechanical handgrip dynamometer (Takei Kiki Kogyo - TK 1201) accurate to 0.5 kg. The dynamometer was adjusted to the gymnasts’ left hand size to obtain their best performance as prescribed by Schlüssel et al. (2008). The subjects were instructed to squeeze the dynamometer’s handle as forceful as possible and to hold it for 5 seconds (Balogun et al., 1991). Three trials were conducted (Häger-Ross & Rösblad, 2002) with 2 to 5 minutes of resting intervals were allowed between testing in order to overcome fatigue (Balogun et al., 1991). The highest value (kg) was used to represent handgrip strength (Balogun et al., 1991; Häger-Ross & Rösblad, 2002). All tests were supervised by the same observer and to assess intra-observer reliability, 15 gymnasts were evaluated twice in the left hand (retest) in a blind fashion within a time interval of one week. The intra-class correlation coefficient was R = 0.990, 95%IC=0.972 to 0.997.
2.2.5. Training data

Training data such as ‘starting age’ (i.e., the chronological age at which formal gymnastics training started) and number of ‘training hours per week’ (h/week) were collected individually by interview with coach’s supervision and checked at the time of data collection. Training years were calculated from the gymnasts’ chronological age at time of the study minus his/her starting age.

2.3. Data analysis

We have considered all gymnasts as a single group assuming that the ‘impact’ of training and body composition in the UV phenomenon is based on the same mechanisms for both male and female.

Descriptive statistics (Mean + SD) were calculated for biological and training variables.

A dependent t-test was used to determine significant changes in PRPR and DIDI as well as ANCOVA controlling for chronological age at baseline.

The UV variations between the two evaluation moments were calculated according to the following formula: \( \text{dif}_{\text{PRPR}} = \text{PRPR baseline} - \text{PRPR at the end of the study} \), and the same was done for DIDI.

Pearson correlation coefficients were used to associate baseline values in PRPR and DIDI with their changes, and between UV and biological/training characteristic. Individual UV changes between the two considered moments were computed by the difference between initial and final measurements (\( \text{dif}_{\text{PRPR}} \) and \( \text{dif}_{\text{DIDI}} \)).

Finally, frequency distributions in UV categories in PRPR and DIDI were tested with a chi-square (\( \chi^2 \))

3. Results

The descriptive statistics for all variables are presented in table 1.
Table 1 – Descriptive statistics of biological and training characteristics in immature Portuguese artistic gymnasts (n=25) at two measuring points in time.

<table>
<thead>
<tr>
<th></th>
<th>1st Mean ± SD</th>
<th>1st Min / Max</th>
<th>2nd Mean ± SD</th>
<th>2nd Min / Max</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biological characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronological age (yr)</td>
<td>10.40 ± 1.74</td>
<td>7.2 / 14.1</td>
<td>11.86 ± 1.75</td>
<td>8.6 / 15.5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Skeletal age (yr)</td>
<td>9.85 ± 1.77</td>
<td>6.1 / 13.0</td>
<td>10.58 ± 1.91</td>
<td>7.1 / 14.0</td>
<td>0.001*</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>32.67 ± 6.86</td>
<td>22.6 / 45.8</td>
<td>38.83 ± 9.32</td>
<td>26.0 / 56.8</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>137.48±10.21</td>
<td>122.5/154.7</td>
<td>146.78±10.73</td>
<td>129.5/165.5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.03 ± 1.59</td>
<td>14.6 / 21.2</td>
<td>17.82 ± 2.01</td>
<td>14.5 / 22.0</td>
<td>0.001*</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>18.02 ± 3.35</td>
<td>11.9 / 24.6</td>
<td>17.12 ± 3.36</td>
<td>11.1 / 23.9</td>
<td>0.044*</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>26.04 ± 7.01</td>
<td>6.6 / 38.9</td>
<td>32.26 ± 8.24</td>
<td>21.2 / 49.8</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Handgrip-L (kg)</td>
<td>17.76 ± 5.00</td>
<td>8.0 / 27.5</td>
<td>20.94 ± 7.84</td>
<td>10.0 / 40.5</td>
<td>0.001*</td>
</tr>
<tr>
<td><strong>Training characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours /week</td>
<td>16.96 ± 3.13</td>
<td>10.0 / 21.0</td>
<td>19.28 ± 1.47</td>
<td>17.0 / 21.0</td>
<td>0.001*</td>
</tr>
<tr>
<td>Starting age (yr)</td>
<td>5.28 ± 1.46</td>
<td>3.0 / 9.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years of training</td>
<td>5.36 ± 2.00</td>
<td>1.0 / 9.0</td>
<td>6.86 ± 2.00</td>
<td>2.5 / 10.5</td>
<td>-</td>
</tr>
<tr>
<td><strong>UV characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRPR (mm)</td>
<td>-2.48 ± 1.71</td>
<td>-8.00 / 1.00</td>
<td>-0.12 ± 2.00</td>
<td>-5.00 / 4.00</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>DIDI (mm)</td>
<td>-3.48 ± 1.56</td>
<td>-8.00 / 0.00</td>
<td>-1.46 ± 2.56</td>
<td>-8.00 / 3.00</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

*p ≤ 0.05

As expected, over a period of time, almost all biological and training variables showed a significant increase in the mean values (p < 0.05), except in the percentage of body fat which showed a reduction (p=0.044).

Gymnasts showed significant UV changes between the 1st and the 2nd moments in PRPR (difPRPR) whose mean value was -2.36 ± 1.89, ranging from negative to neutral UV, i.e., from -2.48 to -0.12 mm (p < 0.001). In spite of the significant differences between both evaluations, DIDI revealed that gymnast’s wrists
Does age and training affect ulnar variance?

remain negative: ranging from -3.48 to -1.46 mm (\(p = 0.001\)) with a difference of 
\(-2.02 \pm 2.64\) between the 1\(^{st}\) and the 2\(^{nd}\) moment in DIDI (\(\text{dif}_{\text{DIDI}}\)).

PRPR\(_{2nd}\) were significantly associated with baseline PRPR values (\(r = 0.494, p = 0.012\)), although the same couldn’t be observed for DIDI (\(r = 0.251, p = 0.227\)). So, regarding DIDI, there were significant changes between the 1\(^{st}\) and 2\(^{nd}\) moments but without association between them.

A significant interaction at baseline was found between age (a covariate) and the time effect in PRPR (\(F= 5.77, p= 0.025\), explained variance (\(\eta^2\)) = 0.201) as well as in DIDI (\(F= 7.06, p= 0.014, \eta^2 = 0.235\)). Regardless of the gymnast’s age, almost all gymnasts showed changes in PRPR and DIDI values during the observational period.

Intraindividual changes (time 1 minus time 2) after an 18 month period in each gymnasts’ UV (PRPR and DIDI) are represented in Figures 2 and 3.

Figures 2 and 3 - UV (PRPR and DIDI) intraindividual changes organized according to gymnast’s age.

Chronological ages (ranging from 7 to 14 years) were described in ascending order. The pattern representative of the change seems to repeat itself in different age classes. In PRPR there is the suggestion of three groups: from 7 to 9 years, at 10 and above 11 years. In the variable DIDI there is the suggestion of two groups: between 7 and 10 years and over 11 years.

The gymnasts with bigger difference in PRPR (5.5 and 5.0) have presented more negative PRPR\(_{1st}\) and DIDI\(_{1st}\) values (-8.0 e -5.0mm, for PRPR and -8.0 e
Does age and training affect ulnar variance?

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-6.0 for DIDI, respectively). The biggest differences in DIDI were 7.0 and 4.5mm.

The gymnasts exhibiting the highest UV variation belong either to the youngest or to the oldest group.

Table 2 shows the frequency distribution within the different UV categories (negative, neutral, positive).

Table 2- Frequency distribution within the different UV categories in Portuguese skeletally immature gymnasts (n = 25).

<table>
<thead>
<tr>
<th>PRPR$^{2nd}$</th>
<th>PRPR$^{1st}$</th>
<th>DIDI$^{2nd}$</th>
<th>DIDI$^{1st}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Negative</td>
<td>Neutral</td>
<td>Positive</td>
</tr>
<tr>
<td>Negative</td>
<td>20</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>30%</td>
<td>55%</td>
</tr>
<tr>
<td>Neutral</td>
<td>5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>0%</td>
<td>60%</td>
</tr>
<tr>
<td>Positive</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>24%</td>
<td>56%</td>
</tr>
</tbody>
</table>

$\chi^2 = 2.708, \ p = 0.251$  \hspace{1cm}  $\chi^2 = 11.413, \ p = 0.003$

Observed frequency changes in the negative and neutral PRPR were not significant ($p = 0.251$), but the DIDI frequencies evolves significantly in their UV categories ($p = 0.003$). From 23 gymnasts with negative DIDI$^{1st}$ values, 13 remain negative, while 8 changed for neutral and 2 became positive.

Correlations were performed between PRPR/DIDI measures and the biological/training characteristics in both evaluations, also for the differences between both UV measures and the values from the 1st and 2nd moments (Table 3).

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Table 3 – Pearson correlation coefficients between UV and biological/training characteristics in immature Portuguese gymnasts at two moments (n = 25).

<table>
<thead>
<tr>
<th>Biological characteristics</th>
<th>PRPR&lt;sub&gt;1st&lt;/sub&gt; 1st</th>
<th>PRPR&lt;sub&gt;2nd&lt;/sub&gt; 2nd</th>
<th>diffPRPR</th>
<th>DIDI&lt;sub&gt;1st&lt;/sub&gt; 1st</th>
<th>DIDI&lt;sub&gt;2nd&lt;/sub&gt; 2nd</th>
<th>diffDIDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chr. age (yr)</td>
<td>-0.306</td>
<td>0.140</td>
<td>0.424*</td>
<td>0.429*</td>
<td>-0.248</td>
<td>0.339</td>
</tr>
<tr>
<td>Skel. age (yr)</td>
<td>-0.215</td>
<td>0.166</td>
<td>0.341</td>
<td>0.501*</td>
<td>-0.237</td>
<td>0.368</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>-0.480*</td>
<td>-0.020</td>
<td>0.443*</td>
<td>0.389</td>
<td>-0.333</td>
<td>0.185</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>-0.351</td>
<td>0.024</td>
<td>0.347</td>
<td>0.329</td>
<td>-0.216</td>
<td>0.247</td>
</tr>
<tr>
<td>BMI (kg/m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>-0.505*</td>
<td>-0.077</td>
<td>0.501*</td>
<td>0.376</td>
<td>-0.397*</td>
<td>0.063</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>0.354</td>
<td>0.203</td>
<td>-0.145</td>
<td>-0.172</td>
<td>0.164</td>
<td>0.190</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>-0.282</td>
<td>-0.062</td>
<td>0.179</td>
<td>0.393</td>
<td>0.157</td>
<td>0.140</td>
</tr>
<tr>
<td>Handgrip-L (kg)</td>
<td>-0.606*</td>
<td>-0.139</td>
<td>0.460*</td>
<td>0.352</td>
<td>-0.457*</td>
<td>0.069</td>
</tr>
<tr>
<td>Training characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours /week</td>
<td>-0.331</td>
<td>0.069</td>
<td>0.151</td>
<td>-0.091</td>
<td>-0.440*</td>
<td>0.203</td>
</tr>
<tr>
<td>Starting age (yr)</td>
<td>-0.194</td>
<td>-0.266</td>
<td>-0.106</td>
<td>-0.106</td>
<td>-0.030</td>
<td>-0.221</td>
</tr>
<tr>
<td>Years of training</td>
<td>-0.094</td>
<td>0.324</td>
<td>0.429*</td>
<td>0.429*</td>
<td>-0.183</td>
<td>0.429*</td>
</tr>
</tbody>
</table>

*p ≤ 0.05; **p ≤ 0.01

The PRPR values presented a reverse association with weight, BMI and handgrip strength at the 1st evaluation moment (r = -0.480, -0.505 and -0.606, respectively). However, at the 2nd moment no correlation was found involving any biological or training characteristics. Although we didn’t find a correlation between PRPR and both chronological age and years of practice in the two evaluation moments, the diffPRPR was indeed associated with these two variables on the two moments (r = 0.424 and 0.429 for chronological age; r = 0.429 for years of practice). It was also observed an association between diffPRPR in the 2nd moment and skeletal age (r = 0.501). The diffPRPR also revealed an association with the heavier gymnasts, with higher BMI and with more handgrip strength at the 1st evaluation moment (r = 0.443, 0.501 and 0.460, respectively).

Concerning the UV parameter DIDI, in the first evaluation there were reverse associations between DIDI and BMI (r = -0.397), handgrip strength (r = -0.457) and training hours/week (r = -0.440). In the 2nd evaluation DIDI only was
associated with the years of practice \( r = 0.429 \). The \( d_{DIDI} \) was associated with skeletal age \( r = 0.423 \) and 0.511), chronological age \( r = 0.469 \) and 0.474) and years of training \( r = 0.524 \) and 0.524) in both moments, and with body mass \( r = 0.406 \) and BMI \( r = 0.421 \) only in the 1st evaluation.

4. Discussion

Since there were no significant differences in UV between males and females \( p = 0.105 \) in PRPR and \( p = 0.485 \) in DIDI) in our research, we decided to study all the gymnasts as a group and not according to gender. Similarly, several authors failed to find a significant relationship between UV measurements and gender in both immature and mature reference populations (Hafner et al., 1989; Schuind et al., 1992; Freedman et al., 1998; Chen & Wang, 2008; Yoshioka et al., 2007), even when comparing the two extremes of their range (-3.8 to +2.3 mm in males and -4.2 to +1.6 mm in females) (Schuind et al., 1992).

At the baseline of our research the Portuguese gymnasts presented a negative UV mean, in accordance to other studies also related to the bone immaturity from gymnasts (Amaral et al., 2012a; 2012b; De Smet et al., 1994; Claessens et al., 1996; Claessens et al., 1997; Claessens et al., 1998; Claessens et al., 2003; DiFiori et al., 1997; DiFiori et al., 2002a), and in agreement with other research with non-gymnasts population (Hafner et al, 1989).

However, after 18 months the results from our sample became significantly less negative, whose trend is similar to several longitudinal studies also regarding immature gymnasts (DiFiori et al., 2001; DiFiori et al., 2006; Dwek et al., 2009).

Nevertheless, there are studies which have presenting a different UV trend in gymnasts (Claessens et al., 1997) and non-gymnasts populations (Hafner et al., 1989), pointing out that the negative values of UV becomes more pronounced with increasing age. So, different trends have been noted in the literature concerning the development of UV in cohort studies of skeletally immature gymnasts.

Therefore, based on the literature related to this subject in gymnasts is possible to consider as dominant the trend towards to a less negative UV with increasing
age. The UV trend to be more negative with the increasing age may be explained due to the different timings of bone fusion of radius compared with ulna’s physis (Dwek et al., 2009).

The ulnar physis appears to lose its growth potential earlier than the distal radial physis, when compared with the standards from the Gruelich and Pyle method of bone age measurement, which may explain the trend to the increase of negative UV with increasing age (Beunen et al., 1999; Dwek et al., 2009). For this reason, the youngsters more advanced in maturity (superior bone ages) have higher probability of presenting more negative UV' values. Regarding this topic, it is important to mention that several authors argue that this is not the usual pattern in the gymnasts’ population (Roy et al., 1985; Mandelbaum et al., 1989; Caine et al., 1992; De Smet et al., 1994; Chang et al., 1995; DiFiori et al., 2006). Therefore, there are differences in the change patterns of UV values between gymnasts and general population (DiFiori et al., 1997; DiFiori et al., 2002a; Dwek et al., 2009).

Gymnasts present a trend that indicates more positive UV values over a period of time that may be related with the interaction between the age and training practice. Additionally, the chronological and skeletal age are significantly associated with the UV changes (ranging from $r = 0.423$ to $r = 0.511$). Nevertheless, when analyzing individually UV measurements at each moment (1st and 2nd data collection) we didn’t find any relationship between chronological or skeletal age and UV (ranging from $r = -0.306$ to $r = 0.368$).

Similarly, several reports based on cross-sectional designs claim that changes in relative ulna’s length in immature gymnasts were not significantly related to chronological age (De Smet et al., 1994, Claessens et al., 1996; DiFiori et al., 2002a; Claessens et al., 2003, Amaral et al., 2012a; 2012b), or to skeletal age (Amaral et al., 2012b; Claessens et al., 2003).

So, we can present several questions related with this subject: can age, per se, be an influent and decisive factor in UV change? Is the training an equally predisposing factor to the morphological changes in the radius and ulna? Is there any interactivity between age and time effect in UV? In this context, in order to observe the interaction between age and time effect in UV, reducing the age interference, data was homogenized adjusting the age to other
variables (ANCOVA) resulting in significantly UV differences during a 18 months period in PRPR (p= 0.025) and in DIDI (p= 0.014).

Hypothetically, age is not the only variable causing changes in UV. Other variables such as factors related with training and aspects that may overload the wrist may be influencing this process.

The changes in the relative length between ulna and radius were very often attributed to the training loads. It is often claimed for several authors (Mandelbaum et al., 1989; Caine et al., 1992; De Smet et al., 1994; Chang et al., 1995; Caine et al., 2006; DiFiori et al., 2006) that the repetitive loads in the radial epiphysis before skeletal maturity, leads to a premature closure of the growth plate and consequently a predisposition to positive UV.

Hours and years of training can be considered the training variables that may predispose overload of the wrist, among others. These variables can be influenced by the biological characteristics (weight, stature, BMI, %Fat, FFM, handgrip strength) which may aggravate the wrist load.

In mean, our gymnasts exhibited a significant increase (p = 0.001) of training hours per week during 18 months, accordingly to the training regimens of young gymnasts which are characterized by high duration and intensity which have been increased throughout the years (Caine et al., 1992; Caine et al., 1997). Regarding possible correlations between training and UV, we didn’t find any association between UV changes and hours/week of training, in contrary we found an inverse correlation between DIDI$^{1st}$ and hours of training per week ($r = -0.440$). In other studies with gymnasts no associations were observed between UV and training (Amaral et al., 2012a; Claessens et al., 1996 Claessens et al., 1997; DiFiori et al., 2002a).

However, the years of practice of the Portuguese gymnasts were significantly correlated with two UV parameters ($r = 0.429$ for PRPR e $r = 0.529$ for DIDI). These results were expected because gymnastics is a sport which involves periods of substantial upper extremity support, as well as frequent impacts in the wrist (Markolf et al., 1990), and may contribute to modifications in the length of the radius and the ulna.
Experimental Work

Does age and training affect ulnar variance?

If small changes in UV can have major effects on the force transmission across the wrist (Ertem et al., 2009; Laino, Petchprapa & Lee, 2012; Markolf et al., 1990; Bu et al., 2006), we may expect that different categories in UV (positive, neutral and negative) will react differently to the wrist loads.

The UV change in the Portuguese gymnasts’ wrists, was not uniform at the individual level and also in what concerns to the frequency of the UV categories.

At the individual level the higher variability of UV happened in the wrists with more negative UV and was also observed that UV changes didn’t happen linearly with chronological age, in accordance with the results from Freedmam et al. (1998).

Taking into account the different categories, 48% of the DIDI measures have changed significantly during the observational period, in contrary to the PRPR ($p = 0.003$ vs. $p = 0.251$, respectively), in agreement with findings from Chang et al. (1995), ranging from 23.6% in the 1st year of training to 81% in the 8th year of training. However, there were some differences concerning samples and methods used between our research and Chang et al. (1995). Portuguese gymnasts’ wrists showed more negative UV values ($-3.48\text{mm} \pm 1.71$) when compared to the Chinese sample (Chang et al., 1995), in which the UV baseline was neutral ($0.07\text{mm} \pm 1.44$). Our study used the Hafner’s method (Hafner et al., 1998) and Chang’s research (Chang et al., 1995) the perpendicular method, without distinguishing between PRPR and DIDI.

As mentioned before, the load may influence the UV changes. Therefore, body weight, as well as other biological characteristics may also be associated with UV and our results showed that UV changes are related with weight and initial BMI These means that the higher the weight and the BMI, the more significant the UV change is, which may agree with Emery (2003) when state that heavier gymnasts are more likely to be injured due to the high forces absorbed by musculoskeletal system. Claessens et al. (1996) also claims that gymnasts who have higher mechanical load on the wrists, have a greater predisposition to develop positive UV. Several other authors (Amaral et al., 2012a; Claessens et al., 2003; De Smet et al., 1994) have observed significant positive association between UV and weigh in female gymnasts, despite the fact that DiFiori et al. (1997) couldn’t find a relationship between these variables.
Because during several gymnastics skills the gymnast’ wrists support forces varying from two to four times body weight (Markolf et al., 1990; Davidson et al., 2005; Burt et al., 2010), the tolerance limits of the growing structures could be exceeded by the specific and frequent demands of the sport (Roy et al., 1985; Caine et al., 1992; Caine et al., 1997), contributing to the pathogenesis of wrist injuries in gymnastics (Markolf et al., 1990).

The radial growth plate injury may involve the zone of osteogenesis, perhaps resulting in temporary cessation of new bone formation (Dwek et al., 2009). Another factor may be due to the compromise of the blood supply to the metaphysis and/or epiphysis (DiFiori et al., 2006; Webb & Rettig, 2008), which can lead to abnormal endochondral ossification (Gabel, 1998; Webb & Rettig, 2008). Consequently a positive UV may be developed because immature gymnasts presents mainly negative UV and the training loads will be more distributed by the radial distal physis. However, others authors (Claessens et al., 1997) have concluded that gymnastics training does not inhibit the normal grow of the radius, resulting in a positive UV, as previously claimed. So, the thin red line which distinguishes the training load that produces enough stress to induce a beneficial effect and the training load that is too stressful, resulting in injury, has not yet been drawn (Roy et al., 1985). The effect-response to mechanical loading is not well known, since changes in histomorphometric parameters in dynamic loading on growth plates are inconsistent (Villemure & Stokes, 2009).

UV is also affected by handgrip strength (Sönmez et al., 2002; Scuurman et al., 2001). In the present study, handgrip from portuguese gymnasts presented an inverse correlation with PRPR and DIDI in the transversal evaluation (1st): the higher the handgrip strength, the higher the association with negative UV. These results are contrary to other authors (DiFiori et al., 2002a) who found no association between handgrip and UV.

Our results also demonstrated a positive association between ‘PRPR change’ and handgrip strength at baseline. Several autours (Cerezal et al., 2002; Schuurman et al., 2001; Sönmez et al., 2002) refer that a strong handgrip result in a significant proximal migration of the radius, leading to an increase in UV. So
Experimental Work

Does age and training affect ulnar variance?

gymnastics movements might change UV momentarily, or eventually contribute to a UV long term change.

More longitudinal and intervention studies are needed, which include a large sample of competitive male and female gymnasts, using periodical wrist radiographs and clinic evaluations to assess the nature and extent of training loads associated with the complex UV phenomenon. It is important to evaluate the bone shape and size area at the distal radius and distal ulna by imaging examination, and associate them to possible skeletal benefits or specific injuries.

5. Conclusions

The average of UV from Portuguese gymnasts changes during a period of 18 months to become significantly more positive (less negative or neutral).

The frequency of different categories in the UV changes is significant in the parameter DIDI, and non significant in PRPR, although with the same trend.

Individually, these changes are not a unique pattern in accordance with the increase in chronological age, and different amplitudes of UV changes are independent of the gymnasts’ age.

Regardless of gymnast’s age, almost all gymnasts showed changes in UV parameters values during the observational period.

Some biological and training variables were association with UV and with their change, like chronologic and skeletal age, body mass, BMI, handgrip strength, and years of training.
CHAPTER IV

GENERAL DISCUSSION
GENERAL DISCUSSION

As mentioned in the above papers the practice of Artistic Gymnastics exposes the wrist to considerable loads by axial compression and bending forces during tumbling, vaulting and beam work for girls and during boys' performances on pommel horse, vault and floor exercise (Markolf et al., 1990; Koh et al., 1992; DiFiori et al., 2006; Webb & Rettig, 2008; Dowthwaite & Scerpella, 2009). The specific characteristics of the exercises performed in these apparatus imply a significant amount of impact on the wrists, making the distal radius physis a common anatomical site for injury in gymnasts due to the load applied on the upper weight-bearing extremity (Webb & Rettig, 2008). For this reason, the wrist pain of gradual onset (microtrauma) is very common in gymnasts of both sexes (De Smet et al., 1993; DiFiori et al., 2006) and because it has a high incidence contributes to reducing the athletes’ performance during training and competition (Caine et al., 1992; DiFiori et al., 2006; Mandelbaum et al., 1989). Despite the several attempts made to understand the predisposing risk factors of pain symptoms, the causes are multifactorial and remain unclear.

In our sample of Portuguese artistic gymnasts (immature/mature and female/male), it was observed an incidence of painful symptoms lower (45.5%) than in other studies exhibiting values mostly between 56% and 79% (DiFiori et al., 2002a; 2002b; DiFiori et al., 1996; Mandelbaum et al., 1989).

Our review article and experimental studies focused on the UV phenomenon and wrist pain, which may eventually be associated with one another and also to training and some biological variables.

**Ulnar variance in a reference population**

Few studies were found in the literature related to UV in a reference immature boys and girls population (Hafner et al., 1989; Chang et al., 1995). Hafner et al. (1989) referred that UV in the immature is on average negative and becomes somewhat more negative with increasing age, ranging from -2.1 to -2.3 mm for PRPR and from -2.3 to -2.8 mm for DIDI.
Ulnar variance in gymnasts

Based on the literature and on our own results, it is possible to state that there is no default value of UV for the immature gymnasts from both sexes. Comparing all data concerning UV from immature gymnasts, a wide range of values can be observed in restricted populations, ranging from -3.6 to +0.5mm for PRPR and from -6.5 to -1.4 mm for DIDI (De Smet at al., 1994, Chang et al., 1995; Claessens et al., 1996; DiFiori et al., 1997; Claessens et al., 1998; DiFiori et al., 2002a; Claessens et al., 2003; Dwek et al., 2009; Amaral et al., 2012a; 2012b). It is interesting to highlight that there are many more studies related to female than to male gymnasts.

With reference to immature gymnasts the Portuguese boys presented, on average, more negative UV compared to American and Chinese gymnasts and the Portuguese girls more negative than gymnasts from several other studies (De Smet at al., 1994, Chang et al., 1995; Claessens et al., 1996; DiFiori et al., 1997; Claessens et al., 1998; Dwek et al., 2009). However, it is possible to find some results similar to our girls (DiFiori et al., 2002a), which are less negative than the results obtained by Claessens et al. (2003).

Based on our two cross sectional studies (Amaral et al., 2012a; 2012b), the total group of Portuguese immature gymnasts showed, on average, negative UV and it seems that UV becomes less negative or neutral with increasing age. This trend evidencing results less negative or neutral with increasing age, could be confirmed in our longitudinal study (Amaral, Claessens, Ferreirinha, Maia, & Santos, 2012c), which was performed with the same sample and the results were similar and statistically significant (p<0.001 for PRPR and p=0.001 for DIDI). Likewise, DiFiori et al. (2001; 2006) observed a mean negative UV at baseline which became significantly more positive. In contrast, Claessens et al. (1997) verified negative values of UV which have become more pronounced with increasing age.

According to DiFiori et al. (2006), it can be demonstrated that during the skeletal maturation process, the negative UV becomes relatively more positive until closure of the growth plate, when it typically becomes neutral. In accordance with the above, the Portuguese mature gymnasts showed precisely neutral UV
General Discussion

values, (-0.10 ± 1.48mm) (Amaral et al. 2012d), contrasting with other studies positive values, ranging between +1.28 and +2.82 (Mandelbaum et al., 1989, De Smet et al., 1994; Chang et al., 1995).

Assuming that the immature individuals from a reference population and gymnasts have negative UV, it is important to know if there are significant differences between gymnasts and non-gymnasts and the factors that may influence those UV changes.

**Ulnar variance in gymnasts versus reference population**

Several authors, mostly with cross-sectional studies, began to evaluate the UV values in gymnasts and compare them with reference values. Difiori et al. (2006) and Dwek et al. (2009) observed that the negative values of UV in male and female immature gymnasts at baseline became significantly less negative than age-appropriate normative values from reference population, that is, UV in gymnasts was significantly more positive than in the general population although within the normal range (Amaral et al., 2012a; DiFiori et al., 1997; DiFiori et al., 2002a; Dwek et al., 2009).

However, Portuguese immature male gymnasts showed a trend towards a more negative UV than normative values from immature population (Amaral et al. 2012b), while Chang et al. (1995) found no significant differences between their gymnasts’ sample and a control group of immature Chinese musicians.

The trend towards a more positive UV was also observed in mature gymnasts. According to the literature, the mature reference population presented UV values ranging between -0.8mm and +0.89mm (Chang et al., 1995; Schuurman et al., 2001; Yeh et al., 2001; Chen & Wang, 2008), while gymnasts showed a UV much more positive (Mandelbaum et al., 1989; De Smet et al., 1994; Chang et al., 1995). It is important to point out that there are much more data concerning mature than immature individuals in the reference population, unlike gymnasts for which there are few data related to mature individuals.

Due to the literature significant differences in UV values, we considered as essential to investigate the reason for theses discrepancies.
Factors related to ulnar variance

Since the beginning we expected that variables related to biological and training characteristics - such as age, sex, body composition (weight, height, BF%), hours of training, starting age, years of training, handgrip strength and even the manual dominance - could be factors inducing a greater load in gymnasts’ wrists, which could modify UV and/or causing pain.

Gender

Our studies revealed that immature female gymnasts had less negative values than immature male gymnasts, however without significant differences between them (Amaral et al. 2012c).

Despite several authors failed to find a significant relationship between UV measurements and gender in immature and mature reference populations (Freedman et al., 1998; Hafner et al., 1989; Schuind et al., 1992; Chen & Wang, 2008; Yoshioka et al., 2007). Jung et al. (2001) and Nakamura et al. (1991) reported that mature females exhibited significantly more positive UV than males.

Anthropometric characteristics

Regarding the relationship between UV measures and bodily characteristics, our studies involving Portuguese gymnasts showed different results between male and female. No significant correlations were observed in immature male (r = -0.38 until r = 0.33) (Amaral et al., 2012b), while in female low significant correlations were observed between DIDI (on the left wrist) and stature (r = 0.23); body weight (r = 0.21), muscle development (r = 0.25) and TW3-skeletal age (r = 0.16) (Amaral et al., 2012a). Although DiFiori at al. (1997) didn’t find a relationship between these variables and UV in male and female gymnasts, other researchers have confirmed a significant positive association between UV and height and weight in female gymnasts (De Smet et al., 1994; Claessens et al., 2003).

Other variables of body composition are likely to influence the UV in gymnasts, such as %Fat, FFM and muscular mass. For some authors there are potential alterations in the distal physis of the radius in gymnasts, especially in those with
high %Fat who may present more pronounced UV (Caine et al., 1992; O'Connor et al., 1996), but Claessens et al. (1996) didn’t find a significant association between UV and variables related to fat development. Claessens et al. (1996) found out that gymnasts who are taller, heavier and with a higher muscular mass, tend to present more positive UV.

Nevertheless, Caine et al. (1992) refer that the short stature and light weight of biologically immature gymnasts yields a biomechanical advantage based on an increased strength-weight ratio, greater stability and decreased moments of inertia, thereby allowing greater facility in gymnasts’ movements. On the other hand, it cannot be concluded per se that weight and/or height or even other somatic components may contribute to changes in UV, regardless of training, genetic characteristics or other variables.

**Dominance / Laterality**

According to several authors, if the positive UV observed in gymnasts is a consequence of the excessive physical load on the wrist, it may be predictable that the dominant hand presents higher positive UV due to the heavier load it suffers. This could cause possible differences in UV, depending on the laterality and the hand dominance.

However, there is no consensus in literature regarding the concepts of dominance and laterality. Some authors refer to dominance as handedness, i.e. the hand preferentially used or performance hand (McManus, 1996), while others consider it as the lateral preference or direction to which individuals spontaneously chooses to perform turns around their body (Golomer et al., 2009). We considered dominance as the first hand placed on the ground while performing a cartwheel (Claessens et al., 1998). The systematic repetition of certain movements and the effect of these load in the most regularly used hand/wrist (dominant hand), is likely to induce changes in UV.

Indeed, when the right hand is dominant and considering both handedness and dominance (rotational direction), the Portuguese female gymnasts demonstrated significant differences between both sides in PRPR ($p \leq 0.01$) with strong associations between them ($r$ from 0.60 to 0.85) (Amaral et al., 2012a). Claessens et al. (1998) didn’t observe significant differences between
dominant and non-dominant wrist and Freedman et al. (1998) and DiFiori et al. (2002a) didn’t find significant correlation between UV and handedness.

Concerning laterality (right vs. left), the Portuguese female gymnasts showed some significant differences between right and left wrists in PRPR \((p = 0.01)\) (Amaral et al. 2012a), which is in accordance with results from Claessens et al. (1998). Also similarly to the same author, we also didn’t find significant differences in DIDI values.

Because UV results may differ between wrists, it is clear that in future studies the measurement of UV in both wrists is recommended and hand dominance should be specified to unravel the nature of the UV complex phenomenon.

**Handgrip strength**

We found a low correlation \((r = -0.42; p \leq 0.05)\) between PRPR-L and its ipsilateral handgrip strength in immature males (Amaral et al., 2012b). In another study performed on female gymnasts (Amaral et al. 2012a) and in accordance with DiFiori et al. (2002a), we didn’t find a significant relationship between UV and handgrip strength. The data from the above-mentioned male study support the premise that gymnasts with more handgrip strength have more negative PRPR.

Handgrip strength affect the UV which can increase significantly (proximal migration of the radius) between 1 and 2 mm, with a strong handgrip motion, illustrating its dynamic character (Tomaino, 2000; Cerezal et al., 2002; Schuurman et al., 2001; Sönmez et al., 2002). The amplitude of these changes may alter the characteristics of mechanical load transfer by more than 25% and probably have particular clinical significance in individuals, as the gymnasts, who perform repetitive rotational manoeuvres with load on the wrist (Mann et al., 1992; Yoshioka et al., 2007).

In our opinion it is important to know the possible cause-effects between handgrip strength and UV, that is, if more handgrip strength may protect the wrists from disorders or lead to UV changes, because stronger handgrip can result from greater use in gymnastics tasks, therefore overload and higher microtraumas.
Training characteristics

Several studies suggest that gymnastics training, with sufficient volume and intensity, may precipitate abnormal changes of the distal radial growth plate and eventually lead to a premature physeal closure and consequent positive UV (Caine et al., 1992; Chang et al., 1995). Based on these possible consequences, it was expected - in accordance to the results of Mandelbaum et al. (1989) - a tendency towards a positive UV over the years as a result of gymnastics training. However, only in immature male gymnasts some significant results ($r = 0.48; p \leq 0.05$) were obtained between DIDI-R and years of training (Amaral et al., 2012b). Concerning immature female gymnasts, in full agreement with the results obtained by Claessens et al. (1996), we also didn’t found significant correlations between UV and training variables (Amaral et al., 2012a).

In fact, most studies did not show significant associations between UV and training variables (DeSmet et al., 1994; Claessens et al., 1996; DiFiori et al. 1997; DiFiori et al., 2002a). Regarding the competition level, DiFiori et al. (2002a) found a significantly higher positive UV in a group of elite compared to nonelite collegiate gymnasts.

The lack of consensus on the cause-effect of training characteristics vs. UV may be explained by some bias on the results due to the different conditions from the referred studies which may clarify some UV oscillations such as the different methods used (MRI, Palmer, Perpendicular and Hafner’s methods), different observers, possible differences in laterality and dominance hands, ethnographic-related factors (Amaral et al., 2011), different competition levels, different chronological or skeletal ages, samples with a reduced number of gymnasts and sometimes analyzing male and female together.

Pain

Because in the wrists with negative UV the charge is distributed mostly in the radial physis, a higher prevalence of pain could be expected in subjects showing a greater negative UV (DiFiori et al., 2006; DiFiori et al., 2002a; Dwek et al., 2009).
General Discussion

Analyzing Portuguese gymnasts (Amaral et al., 2012d), despite gymnasts with negative UV have shown a higher percentage of pain, the pain risk was identical for any type of UV. Also no significant differences were found between painful wrists frequency and the UV values in the immature male gymnasts (Amaral et al., 2012b). Although the immature male gymnasts with wrist pain had more negative PRPR than those without wrist pain, the differences were not statically significant (Amaral et al., 2012b), which is in accordance with data from DiFiori et al. (2002a).

Some authors support the theory that pain represents the first stage of an overuse injury which progressively causes a stress injury in the distal extremity of the radius (growth inhibition), allowing the development of positive UV (DiFiori et al., 2002a; 2002b). Others believe that painful wrist syndrome is frequently the result of the ulna’s overgrowth (positive UV) caused by biomechanical forces inherent to gymnastics activities, which affect negatively the radius distal growth plate (Caine et al., 1992; Roy et al., 1985).

Due to the divergent opinions in the literature and because we also didn’t find any relation between the different UV categories and pain symptoms, there are no evidences proving that a specific UV value may predispose gymnasts to wrist pain.
CONCLUSIONS

Based on the results of the different studies which comprise this dissertation, we establish the following conclusions:

In the literature, several authors have observed UV in the immature reference population having concluded that, in general, UV is negative and may change with increasing age. Despite the prevalence of negative values also in immature gymnasts, there are several reports showing greater incidence of relative and absolute positive UV in the gymnasts’ population and this fact may be associated with training or and biological characteristics.

Throughout the assessment of all of the Portuguese’s gymnasts in the year of 2011/12 (mature and immature), we found out that most UV values were negative (54.5%), while 39.0% were neutral and 6.5% positive.

Analyzing our cross-sectional studies in immature female and male gymnasts, all average UV values were negative with virtually no significant differences between age-groups. However, in our longitudinal study there was a significant difference between the first and the final UV data (collected after 18 months), suggesting that UV might become less negative or even neutral with time.

In Portuguese immature female gymnasts some significant correlations were found between UV and some biological characteristics (skeletal age, stature and fat-free mass), while in immature male gymnasts significant associations were obtained between UV and handgrip strength and years of training.

In the group of female gymnasts there were also some significant differences between UV in right and left wrists. These differences were also observed when the right hand was dominant, considering both handedness and dominance (rotational direction).

Based on data in the literature, the gymnast’s wrist is a place of great incidence of painful symptomatology and injuries. In Portuguese’ gymnasts the wrist pain is common with a frequency of 45.5%. Many authors formulated several hypotheses concerning pain etiology. In all the Portuguese gymnasts of 2011/12, the age is the only determining factor in the risk of developing
Conclusions

symptoms in this joint, being the older athletes 4.8 times more prone to wrist pain than younger gymnasts.

In literature there are divergent opinions regarding the cause-effect relationship between the change in UV and the pain symptoms. In our study, UV was not a determining factor in the pain onset. The difference in length of the radius and ulna did not represent a risk factor for wrist pain.

Concretely, the association between UV values and the occurrence of wrist pain could not be demonstrated in the skeletally immature Portuguese male gymnasts.

In summary, our findings do not directly support the thesis that Artistic Gymnastics training and biological variables or wrist pain present an evident association with UV.
CHAPTER IV

FUTURE DIRECTIONS
FUTURE DIRECTIONS

Our studies present some limitations, particularly the reduced and heterogeneous sample, the compulsory different methodologies used in immature or mature gymnasts and the lack of a control group (mostly cross-sectional design).

Future studies should attempt to clarify whether UV phenomenon is a consequence or a cause of disorders and diseases, including pain, and distinguish the factors which are positively or negatively associated with UV.

It will be of interest to analyze how the combination of the different variables can interact with UV.

Since our results indicated that the UV changes were dependent of age, futures studies should clarify whether an increased age per se may influence UV or if its effects are additive to training.

Because some differences were observed between left and right wrists, we also recommend for future studies the measurement of UV from both wrists with the specification of hand dominance.

Future studies should also analyze the relation between UV and other variables, such as hypermobility, nutritional profile, genetics and, eventually, race.

Furthermore, randomized controlled studies are needed to evaluate the effect of training characteristics in gymnasts which consistently have higher possibility to present positive UV, as usually attributed by the literature.
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FACSÍMILE
ULNAR VARIANCE AND ITS RELATED FACTORS IN GYMNASTS: A REVIEW

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Original review article

Abstract
Ulnar variance is the relative length of ulna in relation to the radius. This morphological variation in the distal epiphyseal structures may lead to symptoms or pathologic changes to the wrist joint. In order to evaluate and quantify distal radioulnar length discrepancy, different imaging techniques are used, depending on the individual’s maturity. The purpose of this review is to summarize the current literature on this subject and to describe ulnar variance trends, taking into account its association with biological and/or training precursors. Our study analyzes the incidence of positive, neutral and negative ulnar variance between gymnasts and the general population (both immature and mature), seeking to identify possible wrist injury risk factors, which usually influence the gymnasts’ health and performance.

Keywords: gymnastics, morphology, wrist, injury.
Ulnar variance related to biological and training characteristics and handgrip strength in Portuguese skeletally immature female gymnasts

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AIM: The aims of this study were to investigate the ulnar variance in a group of skeletally immature female gymnasts of different age and skill level and to investigate the left-right differences in ulnar variance and its relationship with biological and training characteristics and handgrip strength.

METHODS: Thirty-three Portuguese skeletally immature female gymnasts (mean age 11.1 years) of different age-related categories completed a questionnaire detailing their training characteristics. Besides maturation, stature, body mass, and body composition, also handgrip strength of both hands were measured. Left and right ulnar variance was obtained using Hafner’s procedure and skeletal age through the Tanner-Whitehouse 3-method.

RESULTS: Mean skeletal age (10.1±1.9 yr) is one year younger than chronological age (11.1±2.1 yr) and this discrepancy becomes more pronounced with increasing age-category. Gymnasts presented on average 6.1 years of training and 16.7 hours/week. A negative mean value for both the left and right ulnar variance measures was observed (between -1.7 mm and -3.1 mm) but with increasing age-category there is a trend that ulnar variance becomes more positive (between +0.3 mm and -1 mm). Significant differences between right and left ulnar variance were demonstrated. Correlations between ulnar variance and biological and training characteristics and handgrip strength are rather low and not significant, except for skeletal age (r=0.38), stature (r=0.41) and fat-free mass (r=0.48).

CONCLUSION: Despite some significant results the main results of this study do not directly support the thesis that gymnastics training or handgrip strength are associated with ulnar variance.