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The asymmetry of pectoralis muscles is greater in male prepubertal than in professional tennis players

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Abstract
It is generally accepted that preadolescents have a limited capacity to develop muscle hypertrophy in response to exercise compared with older populations; however, studies are scarce and conflicting. The main aim of the present study was to assess if playing tennis is associated with the hypertrophy of dominant pectoralis muscles (PM) in professional (PRO) and in prepubescent tennis players (PRE). A secondary aim was to assess if the degree of asymmetry of PM is greater in PRO than PRE. The volume of PM of both sides was determined using magnetic resonance imaging in 8 male PRO (21.9 years), 6 male PRE (11 years, Tanner 1–2) and 12 male non-active controls (6 adults: 23.5 years; and 6 prepubescents: 10.7 years, Tanner 1–2). PRO and PRE had 15 and 30% greater volume, respectively, in the dominant than in the contralateral PM (P < .01). No significant side-to-side differences in PM volume were observed in the non-active controls (3%, P = .34 in adults and 5%, P = .17 in children). The degree of side-to-side asymmetry in PM volume was greater in PRE than in PRO (P < .05). In conclusion, tennis practice is associated with marked hypertrophy of dominant PM in tennis players, even at prepubertal age, whilst non-active age-matched control subjects display similar volumes in both sides. The larger asymmetry observed in PRE than in PRO may indicate a greater relative loading in the children or increased contralateral hypertrophy in the professionals. This study demonstrates that prepubertal children respond with marked hypertrophy to loading by tennis.

Keywords: Children; pectoralis; muscle size; muscle; tennis players; asymmetry

Introduction
Exercise-induced muscle hypertrophy may help postpubertal children to improve sports performance, as well as cardiovascular and metabolic health and quality of live (McNee, Gough, Morrissey, & Shortland, 2009; Peterson, Saltarelli, Visich, & Gordon, 2014). However, it is accepted that preadolescents have a limited capacity to develop muscle hypertrophy in response to exercise compared with older populations (Faigenbaum et al., 2009). Nevertheless, previous studies cannot be considered conclusive due to low number of participants in training programmes, absence of appropriate control groups and lack of use of gold standard procedures to measure accurately changes in muscle size (Barnouin et al., 2014; Granacher et al., 2011; Nordez et al., 2009)

The most sensitive method to determine changes in muscle size is the assessment of muscle volume (Barnouin et al., 2014; Nordez et al., 2009). Muscle volume can be accurately measured using magnetic resonance imaging (MRI) or computed tomography (CT). MRI has the advantage that it does not use ionizing radiation but has the disadvantage that it is more expensive and time consuming compared to other methods (Nordez et al., 2009). Previous studies on the effects of exercise on muscle size in children have used a variety of procedures including anthropometry (Ozmun, Mikesky, & Surburg, 1994), dual-X-ray absorptiometry (DXA) (McGuigan, Tatasciore, Newton, & Pettigrew, 2009;
Sanchis-Moysi, Dorado, Olmedillas, Serrano-Sanchez, & Calbet, 2010) and ultrasonography (Fukunaga, Funato, & Ikegawa, 1992). In two studies, CT or MRI was used to determine changes in muscle cross-sectional area (CSA), with conflicting results (Daly, Saxon, Turner, Robling, & Bass, 2004; Ramsay et al., 1990). Muscle CSA only gives a rough estimation of the overall muscle volume and may fail to detect regional changes in muscle mass (Barnouin et al., 2014; Nordez et al., 2009). Using MRI to determine total muscle volumes we have recently shown that male prepubertal children may indeed develop muscle hypertrophy in response to exercise (Sanchis-Moysi, Idoate, Serrano-Sanchez, Dorado, & Calbet, 2012). What remains to be determined is whether the potential hypertrophic response in prepubertal children is of a similar or reduced magnitude than that observed in adults.

Gender differences in the hypertrophic response to exercise in prepubertal children have not been studied using MRI. Studies using DXA in peripuberal girls observed exercise-induced increases in lean mass (Kim et al., 2006; Vicente-Rodriguez et al., 2004, 2008). These studies suggested that hypertrophic response to exercise is more accentuated in boys than in girls (Kim et al., 2006; Vicente-Rodriguez et al., 2004, 2008).

Tennis is an excellent experimental model to study musculoskeletal plasticity in response to chronic exercise since both arms are submitted to similar endogenous factors (nutritional, genetic and neurohumoral), but the playing arm is particularly loaded by tennis practice (Ducher, Jaffre, Arlettaz, Benhamou, & Courteix, 2005; Ireland, Maden-Wilkinson, Ganse, Degens, & Rittweger, 2014). Pectoralis muscles (PM) are intensively involved in throwing actions (Escamilla & Andrews, 2009), and pectoralis major muscle volume correlates with throw performance (Akagi, Tohdoh, Hirayama, & Kobayashi, 2014). In tennis, pectoralis major displays a high degree of activity during the service and forehand strokes in children (Rogowski, Rouffe, Lambalot, Brosseau, & Hautier, 2011) and in adults (Elliott, 2006), whilst pectoralis minor contributes to the normal scapular kinematics (Borstad & Ludewig, 2005; Rogowski, Creveaux, Sevrez, Cheze, & Dumas, 2015).

The main purpose of this study was to determine the volume of PM in prepubescent (PRE) and in professional tennis players (PRO). A secondary aim was to assess if the degree of asymmetry of PM is greater in PRO than in PRE. A greater level of side-to-side asymmetry would indicate greater relative hypertrophy of the dominant side.

The hypothesis to be tested is whether playing tennis at prepubertal ages is associated with an asymmetric development of PM with greater volume in the dominant compared to the non-dominant side, with a level of asymmetry comparable to that reached in PRO.

**Methods**

**Subjects**

Fourteen male adults and 12 boys enrolled in the study. Children were randomly recruited from tennis clubs of Gran Canaria (Spain) and one primary school through local announcements. To be included children had to be below 12 years old, healthy, without any chronic disease and free of musculoskeletal conditions or bone fractures. Six of these boys were tennis players (PRE) who had been participating in competitive tennis for a minimum of 2 years (mean 4.8 ± 2.3 years), with a frequency of at least 5 days per week, 12.0 ± 2.1 hours/week. Control children (n = 6) were recruited among children who did not participate in any regular form of exercise, apart from the compulsory physical education curriculum (2 weekly sessions, 45 min each), and were assigned to the control group. Eight PRO were randomly selected during an International Tennis Federation tournament. All PRO started playing tennis before 12 years old. At the start of their career PRO were submitted to tennis training frequencies and volumes comparable to that of PRE (4–6 days a week, 8–14 hours/week). PRO were studied close to the end of the tennis season and had not been involved in any regular strength training programme apart from 4 weeks during the preparation phase of the season (preseason). For comparative purposes, six non-active men (control group) who had never been involved in any regular physical exercise agreed to participate in the study. Table I summarizes the main characteristics of each group. The study was approved by the ethical committee of the University of Las Palmas de Gran Canaria.

**Pubertal status assessment**

Tanner pubertal status was self-assessed with parental guidance using the standard five-scale Tanner stages (Duke, Litt, & Gross, 1980).

**Magnetic resonance imaging**

A 1.5 T MRI scanner (Philips Achieva 1.5 Tesla system, Philips Healthcare, Best, the Netherlands) was used to acquire 8 mm axial contiguous slices from the torax, that is, without interslice separation.
Sagittal, coronal and transverse localizers of the body were obtained to determine precisely the anatomic sites for image acquisition. Transverse MRI images at rest (a breath-hold at mid-expiration) oriented to be perpendicular to the anterior abdominal wall were obtained. Axial gradient-echo T1-weighted MR images were used with a repetition time of 112 ms and an echo time of 4.2 ms, flip-angle of 80° with a 42 cm² field of view and a matrix of 256 × 256 pixels (in-plane spatial resolution 1.64 × 1.64 mm). The body coil was used for image acquisition. The total research time was about 20 seconds, which was within the breath-hold tolerance of all subjects.

The boundaries of the PM were manually outlined slice-by-slice using a specially designed image analysis software (SliceOmatic 4.3, Tomovision Inc, Montreal) as described elsewhere (Lee et al., 2000). Because substantial fusion may be found between pectoralis major and minor in some slices, these muscles were outlined together. A representative example is depicted in Figure 1. The volume of PM was calculated from the acromioclavicular joint to T12-L1 discal level.

One investigator with expert anatomic knowledge and experience in segmentation manually traced all images. The examiner was blinded to arm dominance and to whether images belonged to participants of the tennis or control groups. The intra-observer coefficient of variation in our laboratory is below 2% for trunk, arm and shoulder muscles (Dorado, Calbet, Lopez-Gordillo, Alayon, & Sanchis-Moysi, 2012; Sanchis-Moysi et al., 2010).

### Statistical analysis

Mean and standard deviation of the mean are given as descriptive statistics in the text, and the standard error of the mean in the figures. Differences between sides were assessed using Student’s paired t-tests. Differences between groups were established using analysis of covariance (ANCOVA), with height and weight as covariates, with the Bonferroni-Holm post hoc test. Additionally, the muscle volume of the non-dominant PM was added as a covariate when the muscle volume of the dominant PM was compared between groups (Atkinson & Batterham, 2012). Before the ANCOVA tests, variables were checked for normality using the Shapiro–Wilks test and for variance homogeneity with the Levene test.
Test. Between-groups differences in muscle asymmetry were assessed using independent samples Student’s t-test (statistical power 80%). SPSS package (SPSS Inc., Chicago, IL, USA) for personal computers was used for the statistical analysis. Significant differences were assumed when \( P < .05 \).

Results

Physical characteristics of each group are summarized in Table I.

Differences in each group

The dominant PM had a greater volume than the non-dominant side in PRO and PRE, while in control adults and children both PM had similar volumes (Table II).

Differences between groups

The degree of side-to-side asymmetry was higher in PRE than in PRO (Figure 2). The level of asymmetry was similar in children and adult controls (5% vs. 3%, respectively, \( P = .24 \)). The magnitude of asymmetry in PM volume was greater in PRO and in PRE than in their non-active age-matched counterparts (both \( P < .01 \)).

Compared to adult controls, PRO had greater volume in the dominant \((P < .001)\) and in the non-dominant PM \((P < .05)\). After adjusting for the covariates, these differences remained in the dominant \((515.9 \pm 14.2 \text{ cm}^3 \text{ vs. } 431.6 \pm 17.8 \text{ cm}^3, P < .05)\) and in the non-dominant PM \((495.1 \pm 21.0 \text{ cm}^3 \text{ vs. } 381.5 \pm 25.3 \text{ cm}^3, P < .05)\).

The dominant and non-dominant PM volumes were similar in PRE and control children \((P = .75 \text{ and } P = .46, \text{ respectively})\). After adjusting for the covariates, PRE had greater volume in the dominant PM than controls \((140.9 \pm 4.3 \text{ vs. } 110.7 \pm 4.3, P < .01)\), while no significant between-groups differences were observed in the volume of the non-dominant PM \((106.9 \pm 8.4 \text{ vs. } 112.5 \pm 8.4, P = .69)\).

Discussion

The present study shows that PRO and PRE have greater muscle volume in the dominant than in the non-dominant PM. In contrast, when PM volumes are compared side-to-side in non-active control subjects, adults and children display similar values on both sides. The study also shows that the degree of asymmetry of PM is greater in children than in PRO.

In PRE, the dominant PM had 30% greater volume compared to the contralateral side. The volume of PM had never been measured in children and, therefore, we cannot compare our results with other studies. However, our finding concurs with a previous MRI research analysing the degree of asymmetry of the upper extremity in PRE and non-active boys (Sanchis-Moysi et al., 2012). Sanchis-Moysi et al. (2012) showed that the total volume of dominant arm muscles was significantly higher compared to the contralateral arm (mean 13%), while non-active control children displayed similar volumes on both sides. The study also showed that the degree of asymmetry was greater in the forearm.

Table II. Muscle volumes of the dominant and non-dominant pectoralis (pectoralis major and minor conjointly)

<table>
<thead>
<tr>
<th></th>
<th>Tennis</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant</td>
<td>Non-dominant</td>
</tr>
<tr>
<td>Children</td>
<td>129.1 ± 38.4</td>
<td>102.3 ± 38.1</td>
</tr>
<tr>
<td>Adults</td>
<td>557.1 ± 77.0</td>
<td>486.4 ± 74.8</td>
</tr>
</tbody>
</table>

Notes: Values are expressed in cm\(^3\), mean ± SD. Comparisons are made between dominant and non-dominant sides in each group.
22%) than in the arm muscles (mean 7%) (Sanchis-Moysi et al., 2012). The greater asymmetry observed in PM suggest that this muscle group is particularly overloaded during tennis strokes compared to other upper extremity muscles. In support, using electromyography in young tennis players (9–14 years) Rogowski et al. (2011) observed that dominant pectoralis major displayed very high activity during the forehand stroke (80–100% of isometric maximal voluntary contraction, IMVC) whereas dominant forearm (40–60% of IMVC) and upper arm muscles (biceps brachii and triceps brachii, 15–40% of IMVC) displayed moderate or low muscle activities (Rogowski et al., 2011). Interestingly, the same hierarchy is observed in the degree of asymmetry in muscle volume in the children tennis players (pectoralis minor > forearm > upper arm) (Sanchis-Moysi et al., 2012).

The degree of PM asymmetry in PRO observed in the present study (15%) is similar to that previously reported for the upper extremity muscles (14%) assessed using the same methods in the same subjects (Sanchis-Moysi et al., 2010). In contrast to children (Sanchis-Moysi et al., 2012), when the upper arm and forearm muscles were analysed independently, the PRO displayed a similar magnitude of asymmetry (Sanchis-Moysi et al., 2010). The fact that the PM was remarkably hypertrophied than the upper extremity muscles in children and not in the PRO could be a specific property of this muscle or the consequence of loading patterns, with fast and repeated stretch-shortening cycles (Rota, Morel, Saboul, Rogowski, & Hautier, 2014; Rota et al., 2012). A recent study using MRI showed that the volume of pectoralis major had a significant impact on throwing performance (Akagi et al., 2014). This is in agreement with the known relationship between muscle volume and peak power in adults and children (O’Brien, Reeves, Baltzopoulos, Jones, & Maganaris, 2009).

A unique finding of the present study is that the degree of asymmetry in PM volume is two-fold greater in PRE than in PRO (30% vs. 15%, respectively). Various mechanisms may explain the greater asymmetry of PM observed in children. Studies using EMG showed that tennis players with a lower skill level, such as children compared to professionals, increased PM loading to generate more power during tennis strokes (Elliott, Fleisig, Nicholls, & Escamilla, 2003; Rogowski et al., 2011; Rota et al., 2012). On the other hand, a greater hypertrophy of dominant PM might be an adaptive response to reduce the higher ratio racket weight/PM volume in the children compared to adults (Rogowski et al., 2009). An alternate explanation for the greater asymmetry observed in the children could be some degree of hypertrophy of the non-dominant arm in PRO. In support, a large difference in the muscle volume of non-dominant PM was observed in PRO compared to controls (30%) but not in children (5%, ns), whereas dominant PM volume was significantly higher in both tennis groups (20% vs. 27%, respectively).

Literature regarding the potential of preadolescents to develop muscle hypertrophy with exercise is scarce and conflicting (Cunha Gdos et al., 2015; Moro, Bianco, Faigenbaum, & Paoli, 2014). To the extent of our knowledge, only two studies have directly compared exercise-induced muscle hypertrophy in prepubescents with the older population (Daly et al., 2004; Sanchis-Moysi et al., 2010). Daly et al. (2004) using MRI observed that the CSA of elbow flexor muscles was 6% greater in the playing arm than in the contralateral of prepubertal tennis players, and the degree of asymmetry did not increase with advancing maturation. Sanchis-Moysi et al. (2010) using DXA estimated that 75% of the asymmetry observed in the upper extremity of PRO was attained at prepubertal age. The present study supports that the potential of preadolescents to develop muscle hypertrophy in response to tennis practice is, at least, similar to adults.

PM have a great influence on common overload shoulder injuries and other underlying pathologies in tennis players (Cools, Declercq, Cagnie, Cambier, & Witvrouw, 2008; Kibler & Sciascia, 2010). The pectoralis major is a powerful internal rotator of the humerus that may contribute to develop strength imbalances between the external and internal rotation of the shoulder in young and in elite tennis players (more strength in concentric internal than external rotation), which could increase the risk of shoulder impingement syndrome (Ellenbecker & Roetert, 2003). On the other hand, a large hypertrophy of pectoralis minor may increase the risk of scapular dyskinesis and shoulder impingement syndrome (Borstad, 2008; Borstad & Ludewig, 2005; Rogowski et al., 2015). Future studies are needed to address whether the degree of asymmetry in pectoralis major and minor hypertrophy is related to the risk of shoulder injuries in this population.

The results of the present study should be interpreted considering some methodological limitations. The study was limited to a small population of tennis players. The elite level of the PRO and the difficulty to include prepubescent children in studies using MRI restricted these samples. Also, given that this is a cross-sectional study, it is difficult to conclusively determine causality. Despite these limitations, the present study shows the large potential of preadolescents to develop muscle hypertrophy in the PM playing tennis. It remains to be determined if the
degree of PM asymmetry at prepubescent age may influence the incidence of acute or chronic overloading injuries later in life. It will be worthwhile to collect some data in elite prepubescent children to generate longitudinal epidemiological information to establish the clinical relevance of our findings. Our children developed a remarkable PM hypertrophy with a relatively low participation in tennis. It will be interesting to determine the biomechanical factors implicated in the hypertrophic stimuli for children.

In conclusion, the present study shows that playing tennis during prepuberty is associated with an asymmetric hypertrophy of PM (30% greater volume on the dominant side) compared to a symmetric development in controls. We have also shown that the degree of asymmetry is greater in PRE than in PRO (30% vs. 15%, respectively). The present study shows that, in contrast to prevailing concepts, children have a remarkable potential to adapt to chronic loading with muscle hypertrophy.

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Disclosure statement

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