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Non-dental study of the 'functional matrix' hypothesis*

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Abstract: An exploratory study was undertaken to obtain data on arm measurements of competitive female tennis players (n=30) at three age levels — prepubertal (10-12years), post-pubertal (16-18years) and mature (45-70years). They were matched with persons who did not play with racquets but who had generally played sport (non-racquet sports persons, n=30). Comparisons were to be made between the arms they preferred for playing tennis with their other (non-preferred) arms, and with the arms of non-racquet sports persons. The results suggest that competitive female tennis players differ from non-racquet sports persons, in that these *tennis players have ignificantly shorter preferred forearm bone length and greater preferred forearm girth measurements than the non-racquet persons*, because their preferred forearm length was longer. These findings were most prominent in the post-pubertal group, which indicates a study to explore the Epigenetic hypothesis using arms is justified. The fact that it was less prominent in the older age group could be explained by the observation that the older players did not stroke the ball as aggressively. The results of this study also indicated that there were no significant differences between tennis players and non-tennis players in ponderal indices, preferred grip strength or preferred elbow and wrist widths. Therefore the results suggest that the phenomenon should be studied in, rather than extrapolated to, the maxillo-facial region.

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MeSH words : growth; anthropometry; sports; arm
Key words : functional matrix hypothesis, forearm

INTRODUCTION

The Physical Education profession tends to rely on the basic assumption that 'physical activity conducted under proper conditions favourably affects the growth and development of children' (Rarick 1974). Numerous studies support the hypothesis that physical activity favourably affects growth and development, in terms of physical, mental and social development (Adams 1938, Bailey 1968, Parizkova 1972, Rarick 1973). However many researchers have concluded that physical activity does not appear to influence development, or has a detrimental affect on growth and development (Shephard 1982).

The purpose of this cross-sectional study was to compare active and non-active tennis players for bone and muscle development, in particular the forearm parameters.

The terms growth and development were referred to as quantitative and functional changes which occurred in body cells and tissues (Shephard 1982). A favourable affect was regarded as a positive increase in body cells and tissues of the arm. The measuring of growth and development is not only dependent upon environmental factors, but also genetic influences (Sady and Freedson 1984, Broekhoff 1985). In an attempt to account for genetic influences, preferred arms were compared with non-preferred arms.

Anthropometric measurements are a means of 'expressing quantitatively the form of the body' (Tudor 1981). The arm measures utilised were bone length, widths, girth measures, arm body fat and grip strength of competitive female tennis players. These measurements were compared with the results of non-racquet sport persons. Finally a comparison was made between three age groups :

☐ Pre-pubertals (10 to 12 year olds)
☐ Post-pubertals (16 to 18 year olds)
☐ Mature age (45 to 70 year olds)

Tennis was selected as the medium for physical activity for a number of reasons. They include :
1. it is a popular sport and therefore a large range of subjects was available.
2. it requires the participant to possess an adequate level of fitness, skill, flexibility, strength, agility and endurance, therefore overall muscular activity.
3. at present, very little data is available to describe the anatomical and physiological characteristics of female tennis players (Powers et al. 1982).

The author has a special interest in the topic, since she has participated in competitive tennis for eleven years. The stimulus to investigate arose from observations of a visible difference in the forearms of several of her fellow tennis players preferred and non-preferred forearms. The significance of this observation was considered worthy of investigation.

'To accommodate changing mechanical stress.... all bones in the body are in a dynamic state of growth and resorption throughout life' (Wheater et al. 1979). The growth of bones is influenced by genetic and environmental factors. Environmental factors include exercise (intensity, duration and type), diseases and nutrition (calcium and vitamin D). Genetic influences include body structure and hormonal factors (Sady and Freedson 1984).

Heavy physical activity is believed to enhance appositional growth of long bones (Rarick 1974). However long and frequent compressive forces appear to have damaging effects on endochondral bone formation. Bones are able to continuously adapt to prevailing stresses by remodelling, until a tolerance level, where permanent damage occurs (Rarick 1974).

Skeletal muscle, responsible for voluntary movement, is also in a dynamic state of growth (Cormack 1984). If a muscle is actively exercised over a period of time, individual cells become larger, so the whole muscle enlarges, called hypertrophy (Cormack 1984). The degree of hypertrophy depends on age, sex and the amount of

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tension developed, the intensity and the duration of exercise. The increase in size of muscles is due to increase in length of the myofibrils (Cormack 1984) as well as an increase in the amount of connective tissue and the number of blood vessels within the muscle (Sinclair 1975).

Another striking effect of vigorous activity, is on body composition, that is the proportion of lean body mass and fat deposit. Pariskova (1968) and numerous other studies have clearly shown that children involved with vigorous and regular physical activity, alter their body composition. The changes involve an increase in their lean body mass at the expense of fat (Rarick 1974).

The results of similar studies undertaken in this area have found that with six months of physical activity, increases in girth and breadth measurements of children are evident (Wheater et al. 1979). However a study of skinfold measurements, failed to find a significant difference between preferred and non-preferred arm measurements (Powers et al. 1982). Finally, a significant difference was obtained in preferred forearm circumferences, but not arm circumferences of 'Outstanding female junior tennis players' compared with non-preferred circumferences (Powers et al. 1982).

MATERIALS AND METHODS

Selection of subjects

The subjects for this study were sixty 'healthy' females. These sixty females were divided into :

1. competitive tennis players (n=30)
2. non-racquet sport subjects (n=30)

Three age groups further subdivided the females into;
a. Pre-pubertals — 10 to 12 year olds (n=20)
b. Post-pubertals — 16 to 18 year olds (n=20)
c. Mature age — 45 to 70 year olds (n=20)

Below is a comprehensive list, indicating the sources from which the subjects were obtained from:

A1-Eaglemont Tennis Club
Ivanhoe Girls' Grammar School
Eltham High School
East Ivanhoe Primary School
A2-Ivanhoe Girls' Grammar School
Eltham High School
East Ivanhoe Primary School
family friends
B1-State Junior Squad (Camberwell)
Regional Junior Squad (Doncaster)
Eaglemont Tennis Club
B2-Eltham High School
Phillip Institute - Physical Education
family friends
1-Eaglemont Tennis Club
Ivanhoe Baptist Tennis Club
2-H_2O Water Aerobics
family friends.

Criteria for selection

Tennis players were screened and selection was made based on their age, tennis standard and achievements as well as participation levels (hours per week and number of years). An attempt was made to obtain and measure female players who spent a significant number of hours practising per week and competing in a reasonably high level of competition.

Non-racquet sport subjects were selected from a variety of backgrounds, including physically active and non-active females. Nevertheless heights, weights and socioeconomic backgrounds were matched with tennis players. Subjects were also selected to fit under the broad category of in 'good health'.

Procedure

Questionnaire:
Volunteers were required to complete a personal details questionnaire. The personal details consisted of :

- name
- uburb
- date of birth
- medical history
- preferred arm used in writing, sports and skills
- menstrual history

Tennis players also reported on their tennis background :

- number of years participation
- verage number of hours participation per week
- brief description of achievements and standard

(refer attached sample questionnaires for other details)

If any response contradicted with the initial screening, a brief discussion followed to clarify the situation before proceeding.

Measurements

(a) HEIGHT

Subjects were required to remove their shoes. Using a convenient wall, the subject stood with their heels and backs flat against the wall. A perpendicular line was established from the top of the head to the wall. Using the same measuring tape, the height was recorded to the nearest 0·5 centimetre.

(b) WEIGHT

Scales were placed on an even, flat surface. Care was taken to ensure the scales were accurate and reliable. Unnecessary clothing was removed before subjects stood on the scales. The weight was read from the same set of scales to the nearest 0·5 kilogram.

(c) BONE LENGTHS

Subjects bony landmarks were palpated with the use of passive movement. Dots were marked on the appropriate locations.

Total upper limb length
Using the same set of bone calipers, the distance between the tip of the acromion process of the scapula to the tip of the styloid process of the radius was measured, to the nearest millimetre. Subjects were required to stand in a semi-prone position.

Arm length
The distance between the tip of the acromion process of the scapula and the lateral epicondyle of the humerus was measured. The elbow was flexed at 90 degrees, with the forearm parallel to the ground.

Forearm length
The measured distance was from the lateral epicondyle of the humerus to the tip of the styloid process of the radius, in the same position as the arm length.

(d) WIDTHS

Shoulder width
The width was measured using the same set of bone calipers, to the nearest millimetre. The two landmarks were the coracoid process and the acromion process of the scapula.

Elbow width
From a posterior position, the distance between the medial epicondyle and the lateral epicondyles of the humerus was measured.

Wrist width
The measured distance was from the tip of the styloid process of the radius to the head of the ulna.

(e) GIRTH MEASUREMENTS

Arm
Girth measurements were taken midway between the olecranon process of the humerus and the acromion process of the scapula in :
1. flexed position
2. extended position

Forearm
Measurements recorded were from :
a. 2 centimetres
b. 4 centimetres
c. 6 centimetres
below the olecranon process of the ulna.

(f) BODY FAT
Three skinfold fat sites were measured using the same set of skinfold calipers.

Biceps
midway between the olecranon process of the humerus and the acromion process of the scapula, anterior aspect

Triceps
same as for the biceps, posterior aspect

Forearm
4 centimetres below the olecranon process of the humerus, posterior aspect

(g) GRIP STRENGTH
Grip strength was measured for each hand using a grip dynamometer. The straight arm overhead action was explained and demonstrated. Subjects performed the activity twice, with the highest score being recorded.

Calculations
The data was collected and stored within the six groupings in a Minitab program. The statistical analysis included the calculation of :
a. the means and standard deviations.
b. *t*"-tests for dependent samples (p=0·05 was considered significant) (Chase 1976).
c. one way analysis of variance (F"=4·00 was considered significant) (Chase 1976).
Comparisons were also made using graphic representation.

RESULTS

The background characteristics of the selected female tennis players and non-racquet sport subjects, in the three age groups — 10 to 12 years olds, 16 to 18 years olds and 45 to 70 year olds are shown in *Table 1 Figure 1* (age), *Figure 2* (height) and *Figure 3* (weight) graphically show variations in means and standard deviations between the six groups. Although there appears to be similarities in height and weight, there are slight differences.

Table 1
Background characteristics of female tennis players and non-racquet sport control subjects

Variable age groups	Tennis	Non-tennis
	age (months)	age (months)
10 to 12 year olds	139.40∓4.17	146.20∓6.99
16 to 18 year olds	211.00∓11.19	205.20∓11.19
45 to 70 year olds	681.70∓96.20	674.70∓93.20
	height (cms)	height (cms)
10 to 12 year olds	152.65∓5.47	150.60∓9.66
16 to 18 year olds	164.25∓3.60	166.65∓7.91
45 to 70 year olds	162.65∓5.45	161.70∓5.12
	weight (kgs)	weight (kgs)
10 to 12 year olds	41.95∓6.42	40.25∓8.79
16 to 18 year olds	60.15∓3.49	57.50∓9.49
45 to 70 year olds	64.70∓4.47	68.00∓7.76

(Mean standard deviation)

Tennis players were slightly taller than non-racquet sport subjects however these results were not significant (F" = 2·51). Comparing weight, tennis players were marginally heavier than non-tennis players, but again not statistically significant (F=0·14). When comparing differences between age groups, significant differences were obtained for height (F=20·69) and weight (F=80·16). The 10 to 12 year old group accounted for the large variation. And finally the 16 to 18 year old age group were taller and lighter than the 45 to 70 females. All groups heights and weights were also compared utilising ponderal indices (height ÷ 3√M weight,Montoye

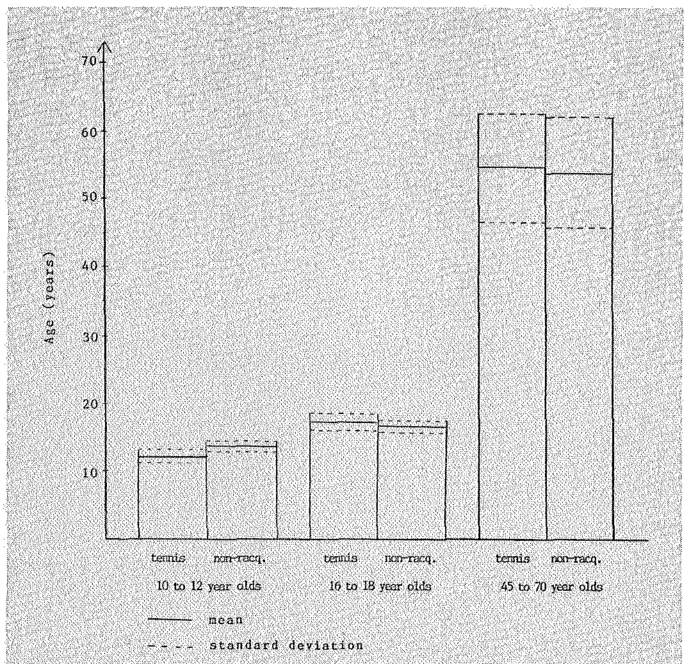

Figure 1. Age means and standard deviations for tennis players and non-racquet sport subjects

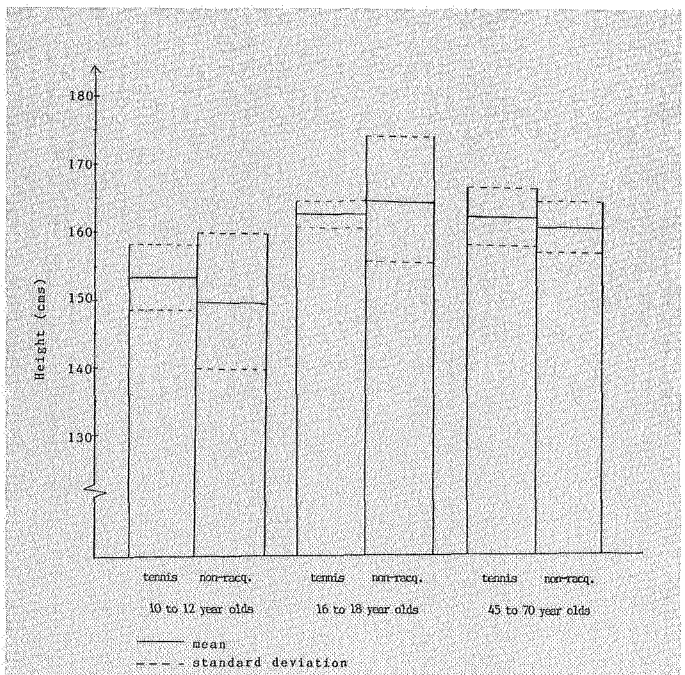

Figure 2. Height means and standard deviations for tennis and non-racquet sport subjects

et al. 1976) *(Table 2)*. There was no difference in ponderal indices between the 10-12 year olds. At 16-18 years, the tennis players were heavier in comparison to the non-racquet sports subjects. The opposite occurred in the 45-70 age group, the tennis players were recorded as being lighter than the non-racquet sports subjects.

Table 3 consists of the means of the measured preferred and non-preferred forearm lengths. Statistical analysis can be interpreted from *Tables 4,5,6* nd *7*.

Preferred and non-preferred forearm lengths were significantly different in non-racquet sport subjects in the two age groups - 16 to 18 years (t=3.39) and 45 to 70 years (t=4.38). In fact, their preferred forearm was longer. Surprisingly there were no significant increase in length of the forearm of the preferred arm over the forearm of the

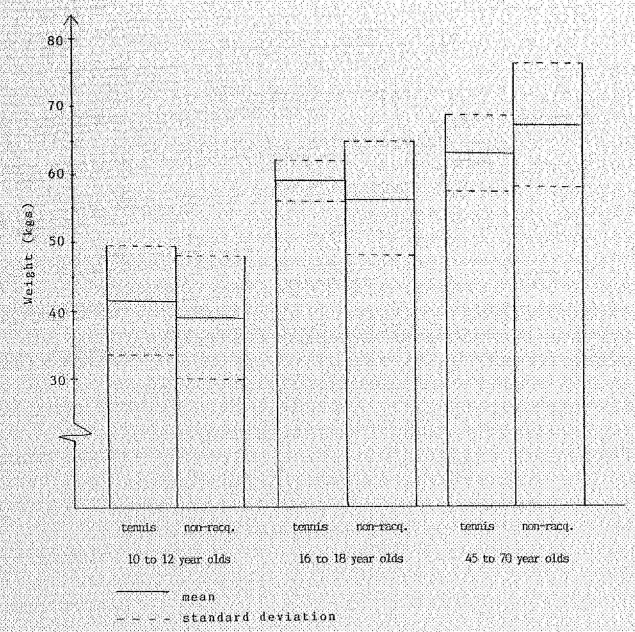

Figure 3. Weight means and standard deviations for tennis players and non-racquet sport subjects

non-preferred forearm lengths in any of the three age groups of tennis players. In fact, the opposite appears to have occurred, the difference between preferred and non-preferred forearm lengths is minimal and even negative in tennis players. That is, the preferred forearm is shorter in tennis players *(Table 4)*

This phenomenon is emphasised by data in *Table 5*. The one way analysis of variance which compared the difference between preferred and non-preferred forearms in tennis and non-tennis players, clearly shows that there is a statistically significant difference between the preferred and non-preferred forearm bone length differences (F = 4.30).

Two other comparisons can be found within *Table 5*, both with regard to forearm bone length. There was a significant difference (F = 14.35), between tennis players and non-racquet sport subjects preferred forearm lengths, however there was no significant difference (F = 3.71) between tennis players and non-racquet sport subjects non-preferred forearms.

Table 2
Ponderal indices (height/3/weight) of tennis and non-racquet sport persons

Variable Age groups	Tennis ponderal index	Non-tennis ponderal index
10 to 12 year olds	43.9	43.9
16 to 18 year olds	41.9	43.2
45 to 70 year olds	40.5	39.6

Table 3
Forearm bone lengths of female tennis players and non-racquet sport control subjects

Variable Age groups	Tennis forearm bone length (mm)		Non-tennis forearm bone length (mm)	
	preferred	non-pref.	preferred	non-pref.
10 to 12 year olds	201.5	199.0	227.5	212.4
16 to 18 year olds	220.7	222.8	233.3	227.1
45 to 70 year olds	222.7	215.2	230.3	220.9

To further evaluate the results the following ratios were used :-

1. Height ratio = forearm bone length divided by height.
2. Upper limb ration = forearm bone length divided by upper limb length.

No significant difference (F = 1·37) was obtained for the forearm to height ratio *(Table 6)*. However a significant difference (F = 4·72) was obtained for the

Table 4
Comparison of preferred and non-preferred forearm bone lengths of female tennis players and non-racquet sport subjects.

Variable Age groups	Tennis forearm bone lengths t	Tennis forearm bone lengths p	Non-tennis t	Non-tennis p
10 to 12 year olds	1.46	NS	1.60	NS
16 to 18 year olds	-0.72	NS	3.39	*
45 to 70 year olds	2.14	NS	4.38	*

NS ot significant
* = significant >0.01

Table 5
Comparison of preferred and non-preferred forearm bone length of female tennis players and non-racquet sport subjects

Variable -activity	number	mean pref. forearm	F
Tennis	30	214.97	14.35**
Non-racquet	30	230.37	
	number	mean non-pref. forearm	F
Tennis	30	212.33	3.71
Non-racquet	30	220.13	
	number	mean (pref.-non-pref.forearm)	F
Tennis	30	2.63	4.30*
Non-racquet	30	10.23	

** significant > 0.01
* significant > 0.05
#not significant

Table 6
Ratio of preferred forearm bone length to height (fore./ht.) of female tennis players and non-racquet sport subjects

Variable -activity	Mean fore./ht.	Stdev. fore./ht.	F
Tennis	1.345	0.089	1.37
Non-racquet	2.022	3.165	

Stdev. = standard deviation #not significant

Table 7
Ratio of preferred forearm to total upper limb length of female tennis players and non-racquet sport subjects

Variable - activity	Mean fore./u.l.	Stdev. fore./u.l.	F
Tennis	0.4473	0.0173	4.72*
Non-racquet	0.4658	0.0433	

Stdev. = standard deviation * significant 0.05
fore. = forearm length u.l. #pper limb length

forearm to upper limb ratio *(Table 7)*, which compared tennis players to non-racquet sports subjects.

In order to determine forearm width differences, elbow and wrist skeletal widths, girth measurements, as well as body fat measures were utilised. *Table 8* represents the mean values and standard deviations for elbow and wrist widths. There were no statistically significant differences between tennis players and non-racquet sports subjects, for elbow and wrist widths ($F=0 \cdot 22$ and $0 \cdot 47$ respectively). *Table 9* represents the mean values and standard deviations for body fat measures, again no significant difference ($F=0 \cdot 16$) was obtained between tennis players and non-racquet sport subjects.

Table 8
Elbow and wrist skeletal widths of female tennis players and non-racquet sport players

Variable Arm parameter	Tennis skeletal width	Non-tennis skeletal width	F
elbow	44.53±10.10	45.80±10.89	0.22#
wrist	35.27±9.50	37.05±10.58	0.47

(mean tandard deviation)
#not significant

Table 9
Body fat measure, at 4 centimetres below the olecranon process of the ulna, of female tennis players and non-racquet sport subjects

Variable - activity	Mean body fat	Stdev. body fat	F
Tennis	10.047	3.173	0.16
Non-racquet	10.397	3.604	

Stdev. = standard deviation
#not significant

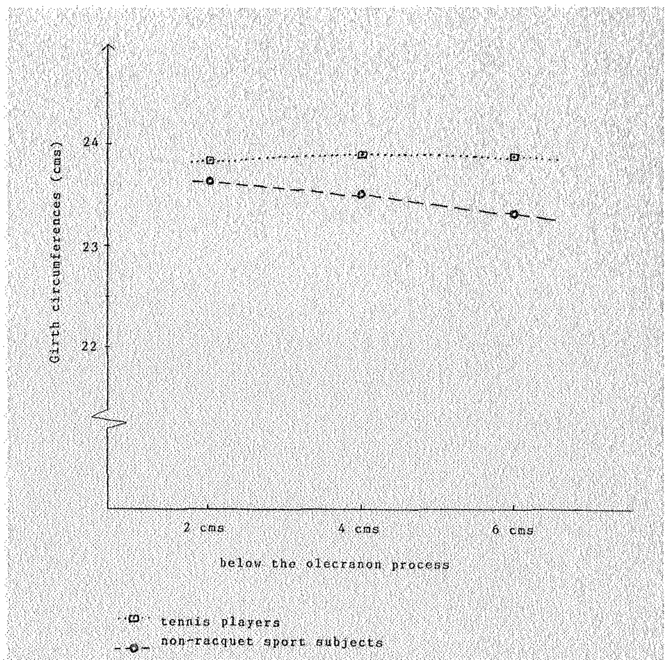

Figure 4. Girth circumference measures of female tennis players and non-racquet sport subjects at 2, 4 and 6 centimetres below the olecranon process of the ulna

Figure 4 represents the forearm girth measurements taken at 2 centimetres, 4 centimetres and 6 centimetres below the olecranon process of the humerus. None of these girth measurements showed a significant difference between tennis players and non-racquet sport subjects ($F=0 \cdot 08$, $0 \cdot 69$ and $1 \cdot 24$ respectively). Nevertheless, the girth measurements did indicate a greater development in the tennis players' forearm.

DISCUSSION

The results of the study are:

1. Height and weight differences were only slight (not significant) within each of the three age groups. There were however, significant differences in height and weight between age groups. The 10 to 12 year old age group accounted for this difference.

2. Using the ponderal index (Montoye et al. 1976), there was little difference between tennis players and non-racquet sport subjects, which is supported by Moffatt et al (1984). There was no difference between tennis players and non-racquet sport persons at 10 to 12 years. At 16 to 18 years, the tennis players were somewhat heavier, indicating an increased muscle mass, either due to increased fat or lean body mass. The 45 to 70 year old tennis players were lighter than the non-racquet sport control group.

Although tennis is a weight bearing sport and requires a component of aerobic fitness, it predominately requires skill, agility, psychology and strength of the participant. A greater weight and thereby greater lean body mass would be helpful in tennis, not only for reaching higher, but also arguably for reaching further to either side.

3. The grip strength was significantly greater ($p=0 \cdot 001$) in all subjects preferred hand compared to their non-preferred hand, whereas there was no significant difference ($F=0 \cdot 01$) between preferred grip strength of tennis players and non-racquet sport subjects.

The significant difference which existed between subjects preferred and non-preferred grip strength is in agreement with data from adult tennis players (Chinn, Priest and Kent, 1974). No significant difference between tennis and non-tennis players conflicts somewhat with the findings of Vodak et al (1980) and Powers and Walker (1982), however similar results were found by Bloomfield et al (1985).

Several investigators have studied the influence of grip firmness on tennis racquets during post impact ball velocity. However these findings have been inconsistent. Missavage and Baker (1984) found that a substantial shortening in the length of the racquet, as well as a greatly increased grip stiffness, was required before a noticeable effect was evident on grip firmness. Thus one might infer that marginal grip strength differences are insignificant. Elliott (1982) showed that while grip strength firmness had little effects on impacts at the centre of percussion, a firm grip was found to be advantageous with regard to off-centre impacts. Clearly more research is required in this field.

4. Tennis players preferred forearm bone lengths were significantly shorter ($F=14 \cdot 35$) than non-racquet sport subjects preferred forearm lengths, whereas there was no significant difference in non-preferred forearms ($F=3 \cdot 71$)

The difference between preferred and non-preferred forearm bone lengths showed a greater and significant difference ($F=4 \cdot 30$) in non-racquet sport persons compared with tennis players preferred and non-preferred bone length difference. In other words, tennis players had smaller forearm bone length differences, and in fact the 16 to 18 year old tennis players preferred forearms were shorter. These results are supported by Booth and Gould (1975) where it was found that after regular intensive exercise for short durations, rats bone lengths slightly decreased. This observed difference could be accounted for by exercise (tennis) having laid greater stress on the bone which led to increased width rather than length *(Figure 4)*.

There was a significant difference (F"=4·72) in preferred forearm to total upper limb ratio between tennis players and non-racquet sports subjects.

5. In wrist and elbow widths, there was definitely no significant difference (F"0·47 and 0·22 respectively) between tennis players and non-racquet sport persons. These results appear to be at variance with Booth and Gould (1975) and Martin et al (1981). The former found that dogs which trained with weights on treadmills, increased their bone mineral content and tibia widths. The results of this study cannot be directly compared with those of Martin et al (1981), because the bone width measured in this study was to the nearest 0·5 cm. on the surface over fascia and skin. Also in this study only one measurement was made, therefore it is strictly not compatible. In order to quantitate the increase in density of bone and its physical parameters, it would necessitate a longitudinal study over a period of time and radiological and histological examinations of the bones involved.

6. Preferred forearm body fat measurements were not significantly different (F"=0·16), comparing tennis players and non-racquet sport subjects. The failure to find any significant difference is in agreement with Gwinup et al (1971) and Powers and Walker (1982).

7. Although there was no significant difference in the girth measurements at 2 centimetre, 4 centimetre and 6 centimetres below the olecranon process of the humerus of tennis players compared with non-tennis players,(in agreement with Powers and Walker, 1982), a greater muscle bulk was evident. This difference was probably caused by muscular hypertrophy, since there were no differences in the fat content *(Table 9)*. Muscular hypertrophy seems to have altered the forearm shape (Vodak et al. 1980), resulting in a well developed muscle belly in the centre of the forearm. This would appear to be extremely advantageous in that a greater force can be transposed into the stroke (Rodrigue and Gaynon 1984).

Although sixty females were measured in this study, they were divided into 2 main categories of tennis and non-tennis players and then further subdivided into 3 age groups. Thus the sample size was ten. One way analysis of variance was used to compare results and accommodate the reduced sample size.

The method and range of selection was limited. The subjects were not wholly randomly selected. Only a few schools - East Ivanhoe Primary, Ivanhoe Girls' Grammar and Eltham High and two tennis clubs - Ivanhoe Baptist and Eaglemont were utilised in this study.

Three main factors which influenced the results of the study were age, growth and physical activity. It is assumed that diet and endocrine factors were normal, and therefore there were no illnesses which interfered with the results.

The age factor accounted for numerous differences in measurements between age groups, however the reason for including the different age groups was to illustrate growth variations. The pre-pubertal females were still growing, so the changes in physical activity were difficult to distinguish due to normal growth. Also this age group did not tend to spend nearly as much time playing tennis as the other two age groups. A rapid phase of growth had just been completed by the post-pubertal females. The effects of activity were expected and found to be very prominent due to the high intensity and duration of the tennis players within this age group. And finally, the mature age group illustrated the effects of continued physical activity. The results indicated that the women who played tennis appeared to be fitter as characterised by their weight, even though they had reduced the intensity of their activity.

CONCLUSION

In summary, this paper has obtained data on upper limb measurements of competitive female tennis players and non-racquet sport persons for preferred and non-preferred upper limbs of pre-pubertal, post-pubertal and mature age groups.

The results suggest that competitive female tennis players differ from non-racquet sport persons, in that they reported a significantly shorter preferred forearm bone length and illustrated greater preferred forearm girth measurements. These findings were most prominent in the 16 to 18 year age group. A functional adaptation of the forearm bone composition appears to have occurred. A possible explanation for this phenomenon is that the increased strength of the muscles has pulled on the bony attachments, thereby resulting in somewhat shorter and stronger preferred forearm bones.

The results of this study also indicated that there were no significant differences between tennis players and non-tennis players in ponderal indices, non-preferred forearm lengths, preferred grip strengths, preferred elbow widths, preferred wrist widths and preferred forearm body fat measurements.

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