THE EFFECTS OF INTENSIVE TRAINING ON THE MUSCULO-SKELETAL SYSTEM OF ELITE YOUNG ATHLETES

Thesis presented for the degree
of Doctor of Philosophy by:

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To those who love me:

at last, they will understand what

I have been up to in the last few years.

ABSTRACT

The effects of intensive training on the musculoskeletal system of 453 elite young athletes practising football, gymnastics, swimming and tennis were followed for two years. The study was a mixed longitudinal design, and five cohorts took part in it, covering the period between nine and 18 years of age. Three aspects were studied, namely injuries, flexibility, and isometric skeletal strength.

Intensively trained elite young athletes did not appear to be injured as often as suggested by an increasing number of recent reports. When they were indeed injured, the impact of the injury, as judged by the time off training taken, was not serious. No incapacitating injuries were encountered during the study, and no athletes were obliged to give their sport up because of injury.

Flexibility was shown to be sport specific, and, to some extent, joint specific. Upper and lower body flexibility were shown to be independent of each other, thus reinforcing the concept of training specificity for optimal sports performance.

Isometric strength of the upper (elbow flexors) and lower body (knee extensors) was within previously described normal ranges, although the athletes in this study were at the highest centiles of the norm.

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3. **J.A. Fixsen, N. Maffulli** Bilateral intra-articular loose bodies of the elbow in an adolescent BMX rider. *Injury* 20: 363-364, 1989.
4. **N. Maffulli.** Intensive training in young athletes. The orthopaedic surgeon's viewpoint. *Sports Medicine* 9: 229-243, 1990.

CHAPTER 1

1.A.1. GENERAL INTRODUCTION

1.A.1. GENERAL INTRODUCTION

The risk of injury is intrinsic to any sport, and the pattern of injuries is specific to specific sports (Yde & Nielsen, 1990). The present view about sporting children and their training routines is that they are not just miniature adults. It should not be assumed that they can demonstrate the same amount and quality of exertion as adults. It is probably safe for the children to follow the 'ten percent rule' (Micheli, 1986), which states that the intensity of any training programme should not be increased more than 10% a week.

Preparation and performance standards should take into account the chronological and biological age of the participants, as well as their physical and psychological immaturity. A better insight into the different aspects of training theory, including duration, intensity, frequency and recovery, are needed to avoid potentially serious damage to the skeletal system of athletic children. When planning a training programme for youngsters, it is important to consider the structural and physiological maturation processes of the growing musculo-skeletal system. Time is needed for the growing child to adjust to these changes, and there is probably little additional capacity for developing speed, strength and resistance (Wojtys, 1987).

1.A.1.1. **GENERAL PURPOSES OF THIS STUDY**

The aim of this study was to establish the distribution, frequency and cause of the positive and negative effects of intensive training within a population of young athletes, with specific reference to sports-related health and injury problems, flexibility and strength.

This thesis describes part of the work carried out with more than 400 young athletes, aged nine to 18 years at the beginning of the study, practising one of football, gymnastics, swimming or tennis at a high level. They were followed up for two years by the author.

For all the procedures described, a pilot study on 32 children was performed four months before the beginning of the main study. All the flexibility and strength measurements, the medical examination, and the injuries questionnaire were administered by the author in all but 13 children in the first year and 19 children in the second year of the study. Anthropometry and pubertal staging were carried out by the author in all boys, except in six boys in year one, and eight in year two. All girls were measured and had pubertal assessments by a trained female anthropometrist, who also measured the boys when the author was absent.

The thesis is divided into three main sections, respectively describing the effects of intensive training on sports injuries, joint flexibility, and skeletal muscle strength.

1.A.1.2. **AN OVERVIEW**

Sports activities impose on the skeletal system forces of a higher intensity and frequency than those associated with normal life. In the past decade, there has been an exercise explosion in the industrialised countries (Davidson & Taunton, 1987), and competitive sport participation has become an established feature of Western children (Rowley, 1986). The magnitude of the phenomenon is partly highlighted by the younger age of the athletes taking part in competition at international level in sports such as tennis, swimming and gymnastics. In practice, children in their early teens may have already undergone intensive training and high-level competition for several years (Maffulli & Helms, 1988; Malina et al., 1982). This is due to the introduction of the "catch them young" philosophy (Rowley, 1986), and to the widespread belief that, in order to achieve international success at senior level, it is necessary to start intensive training before puberty (Maffulli & Helms, 1988).

The number of children taking part in organised competitive sports is so high that some medical bodies have felt the need to issue guidelines to govern participation (American Academy of Pediatrics, 1981; American Academy of Pediatrics, 1982). Concern has been expressed over a potential epidemic of both acute and overuse sports injuries as children change from multivaried free play to the stereotyped demands dictated by the specialised pattern of movement imposed by a single sport at high level (Micheli, 1983; Stanitski, 1985), although the true risk of injury in young athletes is, at present, unknown (Birrer and Levine, 1987; Sahlin, 1990).

The extensive participation in high-level sport by young children begs the question as to what are the effects of training on the developing musculo-skeletal system. These effects are discussed in the remainder of this chapter.

1.A.1.3. **PHYSICAL, CARDIOVASCULAR AND MUSCULAR EFFECTS**

Increases in strength and endurance are an established feature of growth and development (Malina, 1983a) and of training (Ekblom, 1969; Ekblom, 1971; Eriksson, 1972; Saltin & Rowell, 1980). The effects of physical training are difficult to separate from those of normal puberty (Malina, 1982; Malina, 1983a). Studies involving children have demonstrated a wide range of results, from certain ill-effects, such as growth retardation (Delmas, 1982), and no effects at all (Bonen & Keizer, 1984; Kotulan et al., 1980; Malina, 1983b; Rougier, 1982). A certain amount of physical activity is required for normal growth (Malina, 1983a; Delmas, 1982), but the minimum needed has not been identified, and the ill-effects of intensive training have not been fully clarified (Bonen & Keizer, 1984; Kotulan et al., 1980; Delmas, 1982; Malina, 1983a; Malina, 1983b; Rougier, 1982). For example, the skeletal maturation of young male athletes engaged in cycling, rowing and ice hockey was assessed from 12 to 15 years (Kotulan et al, 1980). The authors concluded that regular physical activity had no effect on the growth of young male athletes.

In girls, one of the most sensitive areas of research has been puberty and menstrual disorders (Astrand et al., 1963; Shangold et al., 1979; Warren, 1980). The age of achieving menarche, and the incidence and duration of menstrual disturbances in young athletes engaged in intensive training, have been recently reviewed. With few exceptions, menarche is delayed in athletes (Malina, 1983a; Malina, 1983b; Peltenburgh et al., 1984). Moreover, female athletes engaged in intensive training show an increased frequency of menstrual irregularities (Bonen & Keizer, 1984; Shangold et al., 1979).

The data dealing with this issue have not been convincingly researched. Factors that could influence the time of menarche, such as genetic influences or nutritional status, must be systematically controlled for meaningful conclusions to be made.

There is strong evidence that the response of a given athlete to a particular training regimen is due to an inherited genotype, as only approximately 30% of the maximal oxygen uptake (VO_2max) and maximal force and power of top class competitors can be accounted for by training (Astrand & Rodahl, 1986).

Young athletes undergoing vigorous training have been found to be taller, and to have less body fat and higher VO_2max than sedentary controls (Ekblom, 1971). More recently, 34 boys aged 12-16 engaged in competitive middle and long distance running were compared with 56 controls not undergoing intensive training (Sundberg & Elovainio, 1982). The runners had been training for two to five years, and had less body fat and lower resting heart rate, although statistically significant differences were only achieved at the age of 16 years. The young runners in this study also had larger heart volumes and a higher VO_2max relative to body weight and respiratory capacity.

Another study identified the effects of endurance and sprint training on the vastus lateralis muscles of boys aged 16 and 17 years (Fournier et al., 1982). Endurance training resulted in a significant increase of areas of the more aerobic muscle fibres (type I and IIA fibres), together with increased activity of some of the enzymes of the Kreb's cycle. On the other hand, sprint-trained boys showed a significant increase in the activity of glycolytic enzymes.

A partial drawback of these and similar studies is that they have not controlled for the possible, and indeed likely, selection exerted on these young athletes. The results therefore cannot be readily applied to a randomly selected, non-elite population.

Fewer controlled studies have dealt with the trainability of muscular strength in children. Pre- and post-pubertal children of both sexes can increase significantly their muscular strength following resistance training (Nielsen et al., 1980; Weltman, 1988). The traditional view is that the potential to develop strength is not at its maximum before puberty. Nevertheless, according to Pfeiffer and Francis (1986), pre-pubertal children are likely to have a greater potential for training muscular strength than older age groups. When interpreting the effects of a strength-training programme, one should also allow for the natural increase in strength that occurs in boys approximately one year after the growth spurt, and in girls during the growth spurt itself (Beunen, 1988).

Intensive training may also have negative effects. There have been a number of anecdotal reports of a fatigue syndrome in top class athletes. However, no controlled studies have been performed. Some possible contributory factors include an increased predisposition to viral infections, fatigue from overtraining or combination of physical and psychological fatigue analogous to the "burn out syndrome" reported in other contexts (Anonymous, 1985; Freudenberg, 1974; Marshall & Kasman, 1980). Keast et al. (1988) have suggested that intensive physical training may alter immune responses and thereby play a major role in determining increased susceptibility to infections.

1.A.1.4. PSYCHOLOGICAL EFFECTS

Young competitors undergo increased stress and anxiety due to competition (Smith & Smoll, 1982), and the final result of the competition itself can be positively or negatively influenced by parents (Ogilvie, 1979), potentially leading to a greater incidence of aggression in the young athletes (Sherif & Sherif, 1953). These concerns have led to the extreme position of calling for a complete ban of high level competition in pre-adolescence because of the possible long-term deleterious effects (Sayre, 1975). At present, the effects of intensive training in these youngsters is unknown, even though it is possible to hypothesise that problems may arise in girls with regard to the perceived conflicts between high level sports and feminine image, and in both sexes with regard to various aspects of social life that may be hindered by intensive training routines (Rowley and Maffulli, 1990).

1.B. <u>INJURIES</u>

1.B. **INJURIES**

1.B.1. **INTRODUCTION**

During the period of rapid growth, adolescents are thought to be particularly vulnerable to injuries. According to some authors, this may be partially due to imbalance in strength and flexibility (Micheli, 1983). The large increase in numbers of participants and in the amount of time spent in training and/or competing has meant that children now present with injuries that were previously seen almost exclusively in adults (Hulkko & Orava, 1987; Kvist et al., 1989). There is good evidence that the skeletal system is extremely plastic and shows pronounced adaptive changes to intensive sports training (Dalen & Olson, 1974). The clinical long-term effects of participating in intensive training during the period of growth and development are still obscure. Experimental studies have shown that low-intensity training can stimulate bone length, while high intensity training may inhibit it (Booth & Gould, 1975; Tipton et al., 1972). Intense training may accelerate bone maturation in mice, resulting in permanent suppression of growth in long bones (Kiiskinen, 1987), and circumferential bone growth in chickens is suppressed with exercise at eight and 12 weeks of age (Matsuda et al., 1986). No longitudinal studies have been performed in humans, but a hypertrophic response to long-term overloading of bone has been reported in the upper limb of tennis players (Priest et al., 1977).

Sports injuries may affect both growing bone and soft tissues (Williams, 1981) and, due to the uniqueness of the young athlete's musculo-skeletal system (Wilkins, 1980), they could result in damage to the growth mechanisms with consequent life-long damage (Larson & McMahon, 1966).

The degree of bone mineralization increases with maturation. This implies changes in the mechanical properties of bone as, with increasing mineralization, bone stiffness increases and its ability to absorb sudden loads diminishes (Buckwalter & Cooper, 1987). This is why the pattern of bony injury is different in children and adults. When subjected to sudden overload, normal adult bone generally breaks, while children's bones may bow or buckle, and then may resume their original shape with time.

While physiological repetitive loading is beneficial (Sedhom & Wright, 1988), excessive repetitive efforts at an early age may result in serious alterations of the weight-bearing joint surfaces (Sowinski et al., 1986).

Some large epidemiological studies have shown that 3% to 11% of school-aged children are injured each year when taking part in some form of sports activity (Gallagher et al., 1984; Zaricznyj et al., 1980). Boys appear to be affected twice as much as girls (Crompton & Tubbs, 1977; Zaricznyj et al., 1980) probably because they engage in higher risk sports and have a higher level of sports activity than girls. Physical characteristics can play a major role not only in the choice of a sports, but also on the pattern of injuries (Beaty, 1987). For example, joint laxity is associated with ligamentous injury while tightness is strongly correlated with meniscal injuries and ankle, shoulder and wrist sprains (Marshall & Tischler, 1981). Joint instability is associated with recurrent sprains and dislocations (Lysens et al., 1984). Other factors having an adjuvant role in the occurrence of sports injuries may be the 'extrinsic factors', such as the equipment used and the surfaces the sport is played on (Table 1.B.1.).

Other than the 'usual' injuries, children are said to sustain some bony injuries which are unique to the growing bone (Wilkins, 1980). These are:

1. acute violent injuries
   a. plastic deformation (no apparent fracture seen)
   b. torus fracture (compression of the metaphyseal cortex)
   c. green-stick fracture (intact periosteum)
   d. epiphyseal plate injury
   e. acute apophyseal avulsion
2. stress injuries
   a. microtears of tendon-bone junction

In adolescents, transient loading to joints may also result in so called 'exertion pain'. This is quite frequent, but usually resolves in 6 months without any treatment (Kujala et al., 1986).

A musculo-skeletal lesion is not just a local disorder. Following nociceptor stimulation, muscles contract spasmodically and, as part of a complex system in a finely tuned equilibrium, alter the load distribution on the surrounding structures; further disruption can be caused if appropriate therapy is not promptly started. This is complicated because a large proportion of patients may seek medical help several months after the onset of symptoms (Kannus et al., 1988).

TABLE 1.B.1.

INTRINSIC AND EXTRINSIC FACTORS IN SPORTS INJURIES

INTRINSIC FACTORS	EXTRINSIC FACTORS	
	Exposure	Environment
Age		
Sex	Type of sport	Type and condition of playing surfaces
Somatotype	Playing time	
Personality	Field position	Weather conditions
Strength	Level of competition	Time of day
Ligamentous laxity	Training	Season
Physical fitness	Equipment	
	Protective clothing	

(from Lysens et al., 1984)

Sports activity may cause acute and stress fractures. These will be briefly reviewed thereafter.

1.B.1.1. **Acute fractures**

Bone is an extremely hard derivative of connective tissue. It is a very dynamic tissue which, under overloading, hypertrophies and re-organises its structure to bring mechanical strains to acceptable levels (Montoye et al., 1980). A cyclical load is necessary for bone formation (Lanyon, 1984). If the overload is severe and applied suddenly, a traumatic fracture results. A moderate load, applied fairly often, can result in a stress fracture. The number of times a loading cycle is repeated with the maximum applied stress will determine the ability of a bone to withstand a fracturing force (Cornwall, 1984). A stress fracture can be produced by increased muscle loading at the bone-tendon junction (Altman, 1985). When a muscle is tired, its capability to absorb shocks decreases, and abnormally high repetitive stresses are transmitted to the bone (Nordin & Frankel, 1980). These stresses may interfere with the bone resorption-formation cycle. After the erosion of a lacuna, a layer of cement is deposited. Osteoblasts lay down osteoid, which then takes several weeks to be fully mineralised (Parfitt, 1984). During this period, a bone is more prone to both traumatic and overuse fractures. This observation is of practical importance in children. A dissociation between bone matrix formation and mineralisation during the growth spurt may occur (Bailey et al., 1988; Bailey et al., 1989; Hagino et al., 1990). An intensively-trained child is left with the disadvantages of chronic moderate over-loading, risk of sudden relative great overload, and decreased relative bone strength. This may be the reason why at the age of peak height velocity there is a high incidence of fractures of the distal radius (Bailey et al., 1988; Bailey et al., 1989; Hagino et al., 1990). These authors reported that boys were affected nearly twice as often as girls, with a peak incidence occurring between the ages of 11.50 and 11.99 years in girls, and 14.00 and 14.49 years in boys. The respective peak height velocities occurred at ages 11.85 and 14.27 years. The age of peak fracture incidence did not correspond to the peak activity level in the same population.

Several epidemiological studies have reported the occurrence of acute bone fracture in children involved in sports. The results vary greatly, ranging from an average incidence of injuries per child in the sample considered of about 1% in weight-training (Risser & Preston, 1989) and outdoor soccer (Hoff & Martin, 1986) to 69.8% in wrestlers (Snook, 1982) (Table 1.B.2.).

As can be seen, there are large differences among the different researchers and sports in the incidence of injuries among sporting youngsters. This may be due to several reasons:

1. the different definition of injury;
2. the nature of the study (retrospective or prospective);
3. the data collection system;

4. the exposure to the various sports;

5. the level at which the sport was practised.

TABLE 1.B.2.

FRACTURES INCIDENCE IN SPORTS ACTIVITIES

Sport	Incidence (%)	Total number	Age	Reference
Soccer	2%	681 boys		
		458 girls	6 to 17	Backous et al., 1988
American football	35%	5,128 boys	8 to 15	Goldberg et al., 1988
Various	21%	203 boys		
	21%	114 girls	6 to 11	
	21%	248 boys		
	28%	173 girls	12 to 15	Tursz & Crost, 1986
Various	1%	25,512 mixed	school children	Zaricznyj et al., 1980
Skiers	11.1%	3,534 mixed	3 to 19	Garrick & Requa, 1979
Outdoor soccer	1%	455 boys		
Indoor soccer	6%	366 boys	8 to 15	Hoff & Martin, 1986
Various	23%	295 mixed	0 to 19	Jacobsson, 1986
Various	24.6%	772 boys		
	30.1%	352 girls	6 to 15	Kvist et al., 1989
Various	7%	2,841 boys and girls	5 to 14	Sahlin, 1990
Soccer	2%	931 boys		
		341 girls	7 to 18	Sullivan et al., 1980
Weight training	0.9%	551 boys	* Adolescents	Risser & Preston, 1989
Wrestling	31.2%	353 boys	Collegiate students	Kersey & Rowan, 1983
Wrestling	69.8%	129 boys	~Collegiate students	Snook, 1982

* Fractures and dislocations were considered together.

~ The wrestlers were followed for five years.

1.B.1.2. Stress fractures

Any repetitive activity, no matter how innocuous it may seem, can be a cause of overuse injuries. It has been shown that young adults running at 70% of their maximal oxygen uptake for 40 minutes four times per week sustained a 12% rate of injuries. Those training at 85-90% of their maximal oxygen uptake for 15 minutes three times per week sustained a 22% rate of injuries. Finally, those training at 85-90% of their maximal oxygen uptake for 45 minutes three times per week sustained a 54% injury rate (Pollock et al., 1969).

Stress fractures in children are rare, but their incidence appears to be increasing: in general they are associated with incorrect training (Micheli, 1983). Most stress fractures are likely to be preventable if proper attention is paid to the rate and the intensity of training and its phased introduction (Maffulli & Helms, 1988). Several other factors may contribute to a stress fracture including tight muscle-tendon structure (Jackson et al., 1978; Wiklander & Lysholm, 1987) and altered anatomic alignment (Kvist & Jarvinen, 1982).

Tibia, fibula and metatarsal stress fracture are the most common, but each sport shows a typical pattern of stress fractures (Devas, 1975; Walter & Wolf, 1977) (Table 1.B.3.).

TABLE 1.B.3.

STRESS FRACTURES IN DIFFERENT SPORTS

Sport	Bone affected	Reference
Basketball	Patella	Devas, 1975
	Calcaneum	
	Femur	
	Pubis	
	Hallux sesamoids	Van Hal, 1982
Diving	Tibia	Dowey & Moore, 1984
Fencing	Pelvis	Forcher-Mayr, 1951
Gymnastics	Upper limb	Snook, 1979
Ice skating	Fibula	Devas, 1975
Jogging	Tarsal bones	Matheson et al., 1985
Jumping	Pelvis	
	Femur	
	Navicular	Torg et al., 1982
Rowing	Ribs	Holden & Jackson, 1985
Running	Metatarso phalangeal sesamoid	Hulkko et al., 1985
	Tibia	Hulkko & Orava, 1987
	Fibula	
Tennis	Humerus	Rettig & Beltz, 1985
	Ulna	Rettig, 1983
Throwing	Olecranon	Hulkko et al., 1986
Volleyball	Pisiform	Israeli et al., 1982

The pattern of stress fractures in young athletes is thought to be different from their older counterparts (Harvey, 1982). In the juvenile form, cancellous bone is usually involved, as compressive stresses are applied to trabecular bone and microfractures of these trabeculae develop. In older athletes a stress fracture is generally produced in the more cortical areas (Devas, 1975). There is some evidence that intensively-trained children may exhibit a pattern more similar to the adult type (Micheli, 1983; Donati et al., 1990). Some athletes appear more prone to overuse injuries than others, even though those who train more have a significantly greater number of overuse injuries than those who train less (Orava & Saarela, 1978).

Most of the studies on stress fractures in young athletes have been performed on track-and-field athletes in whom any part of the lower limb and its attachments can be affected. Indeed, three cases of stress fractures of the anterior iliac apophysis in adolescent runners have been described (Clancy & Foltz, 1976). Hulkko & Orava (1987), revising the records of their Sports Injury Clinic, reported about 368 fractures occurring in 324 athletes over four years. Of these, 32 (8.7%) occurred in children less than 16, and 117 (31.8%) in those aged between 16 and 19. Only nine athletes trained less than 3-5 times per week. Running accounted for 72% of the fractures, while all ball games combined showed an incidence of 6.5%. Athletes at international standard suffered from multiple fractures significantly more often than those at lower levels, probably reflecting the greater amount of intensive training they were undergoing. The fractures were diagnosed by clinical examination supplemented by plain radiography and/or bone scanning.

The diagnosis of stress fractures in young athletes relies on radio-isotope bone scanning (Rosen et al., 1982), although magnetic resonance imaging (MRI) has a definite potential in diagnosing stress fractures without subjecting the athlete to ionising radiation.

Rest (Hulkko & Orava, 1987; James et al., 1978) and non-weight-bearing immobilisation (Torg et al., 1982) are the treatment forms most commonly used. Surgery is rarely indicated.

The various components of the skeletal system of young athletes can undergo a variety of injuries, such as osteochondritis dissecans, growth plate injuries, tendinitis and enthesopathy. These have been reviewed in a recent paper by the author, part of the papers bound in this thesis (Maffulli, 1990).

1.C. <u>FLEXIBILITY</u>

1.C. FLEXIBILITY

1.C.1. INTRODUCTION

Flexibility is an important factor in human performance (Cureton, 1941; Singerseth & Haliski, 1949), and stretching and other practices designed to improve flexibility are part of any athlete's routine (Rasch & Burke, 1978). The mobility of a joint is mainly determined by the biomechanical characteristics of its ligaments and of the surrounding connective tissue (Dubs & Gschwend, 1988). Several investigations on joint flexibility have been performed in this century, using radiological (Harris & Joseph, 1949) and arthrographic (Bird et al., 1981) measurements. These include clinical scores (Carter & Wilkinson, 1965; Beighton et al., 1973), an overall index (American Academy of Orthopedic Surgeons 1965) and hyperextensiometry (Dubs & Gschwend, 1988; Jobbins et al., 1979). Generalised joint laxity is an important association in some traumatic and orthopaedic conditions, such as dislocation of the patella and of the shoulder (Carter, 1960), scoliosis (Dubs & Gschwend, 1988) and congenital dislocation of the hip (Wynne-Davies, 1970), while decreased lower limb flexibility is associated with low back pain (Fairbank et al., 1984). A high degree of flexibility is a feature of some sporting activities such as gymnastics (Faria & Faria, 1989; Gabbard & Tandy, 1988) and ballet dancing (Klemp & Chalton, 1989) even though some authors have shown that there is no difference between elite gymnasts and controls before a warm-up session (Bird et al., 1988). In practice, these athletes must be able to reach an extreme range of movement without damaging the surrounding tissues when performing their manoeuvres (Hubley-Kozey & Stanish, 1990). Although not all sports require such range of motion, an athlete must be able to perform the specific movement of the sport practised without excessive soft tissue resistance.

Reports on risks of injury in hypermobile subjects are controversial with some claiming a strong association (Grana & Moretz, 1978; Jackson et al., 1978; Kalenak & Morehouse, 1975; Nicholas et al., 1970a; Nicholas et al., 1970b), while others conclude that increased ligamentous laxity does not increase the risk of injury (Dubs & Gschwend, 1988). Indeed, some studies have shown that soccer players with ligamentous tightness suffer from a greater incidence of muscle injuries (Ekstrand & Gillquist, 1982) which decreased when a stretching program was carried out on a regular basis (Ekstrand et al., 1983). A reduced joint flexibility was encountered in power lifters (Chang et al., 1988) and American football players (Sigerseth & Haliski, 1950) while sports acrobats and swimmers were found to be more flexible than the general population (Brodie et al., 1982). Some groups of athletes, such as ballet dancers, may exhibit imbalanced flexibility (Jacobs & Young, 1978; Singleton & Le Veau, 1959), which could predispose them to painful snapping hip (a disorder in which the fascia lata painfully snaps upon the greater trochanter) and trochanteric bursitis (Reid et al., 1987). Rheumatological and orthopaedic complaints were significantly more frequent in a group of very flexible elite gymnasts when compared to controls (Bird et al., 1988).

In general it seems that hyperlax individuals are susceptible to dislocations, while stiff athletes are more susceptible to tearing injuries (Bird et al., 1988; Nicholas et al., 1970a; Nicholas et al., 1970b). While it has been established that there are definite differences in flexibility in different groups of athletes, it is not clear whether this is genetically-determined or exercise-induced (Chandler et al., 1990). For example, it was shown that, after a 3.5 miles run, there was a significant increase in the torsional laxity of the knee (Stoller et al., 1983). The physiological basis of this phenomenon is uncertain. It is possible that during exercise fluid is squeezed out of the collagen mesh of the articular cartilage, and thus the ligaments become less tight, thus increasing joint laxity. The significance of this phenomenon in determining injuries, and in the long-term increase of flexibility, is uncertain.

The degree and distribution of flexibility in athletes is thought to be important in the genesis and presentation of injuries (Jackson et al., 1978) as, in the normal population, flexibility has been suggested to be specific to each side of the body even in the same joint (Greene & Hillman, 1990). It has been found that gymnasts suffering from low back pain had greater toe-touching ability than those without symptoms (Kirby et al., 1981). A longitudinal study on the relationship between flexibility and injuries was performed on adult amateur ice-hockey players, but the results were unclear (Posch et al., 1989).

The problem of establishing reference values for flexibility, both for adults and children, has only recently been tackled (Pratt, 1989; Svenningsen et al., 1989). For example, the study of the relationship between development and lower limb flexibility in 84 high-school athletes has revealed that pubertal staging, in the manner described by Tanner (1962), had greater predictive value than chronological age (Pratt, 1989). In this study, there was no evidence of any relative deficit in flexibility during the period of maximal linear growth which would account for the higher rates of overuse injuries in adolescent athletes (Micheli, 1983), despite the fact that a clear break in the development of flexibility was identified between Tanner Puberty stage III and IV in both sexes (Pratt, 1989).

There are several possible systems for studying flexibility, namely the American Alliance of Health, Physical Education, Recreation, and Dance (AAHPERD, 1980) or the American Academy of Orthopaedic Surgeons (1965) (Posch et al., 1989; Pratt, 1989). Other techniques are based on goniometry (Ekstrand et al., 1982;

Kirby et al., 1981), linear measurements (Koch et al., 1988), or the battery of functional tests that have been developed by Wiklander and Lysholm (1987).

For this thesis, linear measures were used, which were based on both personal experience and the work of other authors (Koch et al., 1988; Wiklander & Lysholm, 1987). In practice, the TOYA Study required methods that were inexpensive, fast to perform, accurate and reproducible. Moreover, the active rather than the passive range of motion of the joint examined was considered to be important, and the tests had to be easily explained to, and understood by, the children in the study.

Details about the testing procedures are given in the **SUBJECTS AND METHODS** section, Chapter 2.E., pp.85-91.

1.D. <u>STRENGTH</u>

1.D. STRENGTH

1.D.1. INTRODUCTION

Good muscular strength has always been considered desirable. In ancient Greece it was thought that intellectual development was dependent on physical training (Bastholm, 1950). In the 15th century the old Greek ideas were re-discovered, and an Italian, Vittorino da Feltre, devised some tests of muscle strength to be performed on schoolchildren in order to devise programmes for individual training (McCormick, 1943-1944).

In general, strength-testing has been used as an indicator of recovery in athletes after a sports injury (Gauffin et al., 1990; Halkjer-Kristensen & Ingemann-Hansen, 1985), or in sedentary subjects after surgery (Koch et al., 1988). Typically, a group of injured athletes would be followed-up after an injury, and after a given strength-training programme had been undertaken (MacDougall et al., 1980). In order to hasten the return to full participation in training and competition, a period of graduated strength training is considered necessary (Gauffin et al., 1990). Very few studies have considered the possible association between strength and injuries in sportsmen (Posch et al., 1989). These authors showed that a fall in muscle strength during one season of amateur ice-hockey was not related to injury rate. No similar studies have so far been performed in children. This is somewhat surprising as it has been established that a dissociation between bone matrix formation and mineralization occurs at the time of the growth spurt (Bailey et al., 1988). During this period of relative transient osteoporosis, a sporting child may be left at risk of acute or chronic skeletal overload. Furthermore, at the age of peak height velocity, there may be an increase in muscle mass, and an associated increase in muscular strength (Malina, 1983a). This could explain the reported increased incidence of acute apohyseal avulsion sports injuries in this age group (Wilkins, 1980) when compared with the greater incidence of 'pure' bone and ligamentous injuries found in older athletes.

Few normative data are available on the development of muscle strength (Backman, 1988; Backman et al., 1989; Parker, 1989). The first scientific study was undertaken by Quetelet (1835) who used a simple dynamometer to perform a cross-sectional survey of handgrip and trunk strength in 10 boys and 10 girls of each year of age from six years to maturity. His results showed that boys had a marked spurt in strength between 14 and 15 years, while girls showed a similar but less marked trend one year earlier.

Jones (1949) carried out an extensive longitudinal survey of isometric and dynamic strength in children just before World War II. Strength was measured at six-monthly intervals for seven years in 93 boys and 90 girls aged 10 at the beginning of the study.

From the ages of 11 to 13 years there were no significant differences between the sexes but, from 13 years, there was a clear dissociation in favour of boys.

Since this major study measurements of muscular strength in children have not been widely performed. Some cross-sectional surveys of muscle strength in children have been performed (Andersen & Henckel, 1987; Asmussen & Heebohl-Nielsen, 1954 & 1956; Backman, 1988; Backman et al., 1989; Carron & Bailey, 1986; Hosking et al., 1978; Malina, 1974) as well as some longitudinal studies (Beunen et al., 1988; Kemper & Verschuur, 1985). Even less have been carried out in athletic children (Pratt, 1989). Moreover, in several cases strength was assessed using methods which have proved difficult to reproduce, or which include complex manoeuvres requiring the co-ordinated action of more than one muscle or muscle group. In the latter case it is difficult to dissociate the effect of increased skill from that of normal growth. Finally, only some of the above studies have compared boys and girls (Andersen & Henckel, 1986; Asmussen & Heebohl-Nielsen, 1954 & 1956; Jones, 1949; Kemper & Verschuur, 1985). The dissimilarity between the sexes when the absolute strength is expressed per body weight or lean body mass (Andersen & Henckel, 1986; Backman et al., 1989; Davies, 1985) is less evident when expressed per unit cross-sectional area of muscle (Andersen & Henckel, 1986) or of muscle plus bone (Davies, 1985). Recently, no significant difference between the sexes was found when the handgrip performance was related to lean limb volume (Davies, 1990).

A cross-sectional survey of upper and lower limb strength during childhood and adolescence in 267 non-athletic boys and 284 non-athletic girls aged five to 17 years has recently been performed (Parker et al., 1990). The strength of both muscle groups in the boys and girls rose steadily from eight to 12 years. In boys there was a rapid increase in strength in both the knee extensors and elbow flexors even after the end of longitudinal and ponderal growth (Parker et al., 1990). This study showed that for the knee extensors, stretch, as a result of long bone growth, together with loading, are probably the primary stimuli during the pre-adolescent phase of growth. Subsequently, the direct action of sex hormones on the muscle may be responsible for the continuing strength increase in boys. In that study, the testing apparatus was similar to the one used in the TOYA Study; the results obtained in the present study will be compared to it.

There are many factors affecting force production: muscle fibres size, motivation, angle of pennation (or insertion), lever system, the length of the muscle fibres during contraction, the speed at which the contraction is performed, the number of motor units and their activation, fibre type composition and packing of contractile material which changes during childhood and adolescence (Andersen & Henckel, 1987;

Parker, 1989). There is some evidence that some of the above factors may change due to exercise (Astrand & Rodhal, 1986), while for others the effects of physical training are still unclear. The stimuli for an increase in muscle strength are still unclear, even though they may ultimately be under hormonal control (Asmussen & Heebohl-Nilesen, 1954 & 1956). During the process of growth, and especially during puberty, sex steroids and growth hormone may influence muscular development, and this may explain, at least in part, the dissociation in strength between boys and girls at puberty. A tentative analysis of this phenomenon, on a purely physical basis, was performed by Asmussen & Heebohl-Nielsen (1954 & 1956), who had originally suggested that muscular strength should increase with the second power of height and the 0.67 power of weight. Their results, nevertheless, show that strength increases with nearly the third power of height, and so factors other than height and weight influence strength development in children.

More recently, in the pre-adolescent phase of growth, muscle strength of elbow flexors and knee extensors was shown to increase as a function of height squared and cubed, respectively (Parker et al., 1990).

1.D.1.1. **<u>Methods for strength measurement</u>**

In clinical practice, muscular strength is estimated, not measured. In this way, only a coarse grading is obtained, even when the testing procedures are performed by experienced operators under standardised conditions (Brooke et al., 1981).

Under normal conditions, skeletal muscles do not perform isotonic contractions (i.e. contractions during which the force exerted by the muscle remains constant throughout the movement). This is because the demand on the muscles involved when acting against an external resistance varies with the changing angle of the joint on which a given muscle acts (Astrand & Rodahl, 1986). Probably a real isotonic contraction is performed only during an isometric contraction at a given muscle activation, i.e. during a muscle contraction when both the attachment and the insertion of the muscle are fixed and no movement occurs in the joint(s) involved. In this way, no external work is produced in a physical sense (Astrand and Rodahl, 1986). During a dynamic contraction, the muscle may shorten, and in this case the work is termed positive or concentric, or the muscle may lengthen, in which case the work is negative or eccentric. In the case of a dynamic contraction, the amount of physical work performed can be calculated as the product of the force applied multiplied by the distance through which it is expressed. It is measured in Newton metres, Nm. As the distance in an isometric contraction is zero, the mechanical work produced is zero. Nevertheless, biochemical energy is expended, and appears as heat, and may lead to fatigue (Astrand & Rodahl, 1986).

An isokinetic contraction takes place when the angular velocity of a limb segment is kept constant through its range of motion, regardless of the force exerted. This is accomplished using a mechanically regulated device. The isokinetic exercise does not simulate natural movements, except, possibly, swimming (Astrand & Rodahl, 1986). An isokinetic contraction, with a constant angular velocity of a limb segment, does not lead to a constant velocity of shortening of the muscles involved in that particular movement. This is easily explained considering two-joint muscles and muscles following twisted paths. Moreover, the centres of rotation of the joints and of the testing apparatus vary during movement (Astrand & Rodahl, 1986).

Objective muscle force measurement can be performed using the different modalities of contraction outlined above (Astrand & Rodahl, 1986). The cost of the testing apparatus for each contracting modality varies greatly: the least expensive isokinetic testing apparatus on the market at the time of writing is about 200 times more expensive than a strain gauge for isometric testing. Another possible limiting factor of routine isokinetic testing is the amount of time necessary to test a subject, given the necessity to have several testing angular velocities (Maughan, 1984). Nevertheless, an isokinetic dynamometer may be used to test several muscle contraction modalities (Maughan, 1984).

In the TOYA Study measurements of force generation during isometric contraction were used to assess muscle force. In this way, standardisation for length of the muscle and for contraction velocity were made (Parker, 1989; Parker et al., 1990).

1.D.1.2. Isometric contraction

Isometric force is defined as the force developed by a muscle which is not allowed to shorten during contraction as it works against an immovable load. The force output is a function of the tension that the contracting muscle can develop (Astrand & Rodahl, 1986). In all probability, some gliding between the actin and myosin filaments takes place also during isometric contraction and, at the molecular level, the force produced during an isometric contraction is largely dependent on the number of crossbridges between the actin and myosin molecules (Huxley, 1986). During an isometric contraction, the length of the muscle fibres is fixed, and the speed of the contraction is equal to zero, so at least two important factors affecting the capacity of developing strength by a muscle or muscle group are known, and fixed.

Isometric force can be measured either during a voluntary contraction (Backman, 1988; Parker, 1989), or during involuntary contractions caused by supramaximal electrical stimulation of the nerve(s) supplying the muscle (Rutherford et al., 1986). The contracting muscle should be fully activated for at least one second, so that all the motor units of the muscle tested are recruited, thus establishing a tetanic contraction (Backman, 1988; Parker, 1989).

Isometric measurement of muscular strength can be performed with different dynamometers, which can be thus grouped:

1. spring transducers (Hunsicker and Donnelly, 1955);
2. strain-gauge transducers (Edwards et al., 1977);
3. mechano-electric transducers (Dahle, 1954);
4. electronic potentiometer transducers (Penny and Giles Transducers Ltd, England, 1980);
5. pressure transducers (Edwards & McDonnel, 1974; Helewa et al., 1981).

Ideally, a system of muscular strength measurement should be (Helewa et al., 1981):

1. objective;
2. sensitive;
3. reliable;
4. quantitative;
5. reproducible;
6. adaptable to different muscle groups;
7. portable;
8. fast;
9. simple to apply;
10. inexpensive.

However, such a device has not yet been invented, and for this study, a strain-gauge transducer mounted on a portable chair (Jones & Parker, 1989) satisfied most of the above criteria.

CHAPTER 2

2.A. SUBJECTS

2.A.1. The Recruitment of Subjects

Young athletes were randomly selected from a coach-nominated sample from within a 300-mile radius of London. This catchment area was chosen as a compromise between regional bias and practical travelling distance to improve the representativeness of the sample of children taking part.

The age at which young children begin intensive-training varies depending on the requirements of each sport. Therefore the age at which the youngest child entered the study differed from sport to sport. Thus the youngest gymnasts entered the study at the age of eight and the remainder were spaced at two-year intervals up to, and including, 16 years of age. The sample of tennis-players also ranged from eight to 16 years; swimmers 10 to 16 years; soccer- players 12 to 16 years. Because of the longitudinal nature of the research design, by the end of the study data would be available on pre-pubescent, pubescent and post-pubescent children with ages ranging from eight to 20 years of age. Age distribution is shown in Table 2.A.1.

With the exception of football and gymnastics, recruitment of the children was evenly distributed across gender. Far more girls than boys take part in gymnastics and the sample of 100 girls and 50 boys was thought to be a true reflection of participation rates.

TABLE 2.A.1.

PROPOSED AGE DISTRIBUTION

Sport	Age	Number in each cohort	Proposed Sample Size
Gymnastics	8-16	30	150
Tennis	8-16	40*	180
Swimming	10-16	30	120
Football	12-16	30	90
Controls	8-16	40	200

*Except the 1979 cohort (age 9) where only 20 young athletes were to be recruited

The basic criterion for inclusion in the study was that the athletes trained for a specific number of hours per week. These thresholds were provided by National and Regional coaches working in the four sports. Results from the first year indicated a wide-spread variation in the actual number of hours trained by the children. The second criterion was that they had achieved performance success to a specified level in the past or were expected to do so in the future. A data-base of eligible children was developed for each sport, and random samples selected.

Despite the efforts of TOYA personnel and members of the Sports Council Research Unit to obtain lists of intensively-trained athletes from coaches throughout the country, it was not possible to achieve the proposed numbers by sport and cohort group. This shortfall is illustrated in Tables 2.A.2. and 2.A.3.

TABLE 2.A.2.

ACTUAL AGE DISTRIBUTION

YEAR 1

Birth Year	Age	Football	Gymnastics	Swimming	Tennis
1971	17	12	20	24	26
1973	15	25	28	30	32
1975	13	28	28	30	37
1977	11		21	30	39
1979	9		22		21
Total		65	118	114	152

Total sample: 453

Proposed		90	150	120	180

YEAR 2

Birth Year	Age	Football	Gymnastics	Swimming	Tennis
1971	18	10	18	22	25
1973	16	23	18	27	29
1975	14	25	23	27	34
1977	12		20	28	36
1979	10		20		21
Total		58	99	104	145

Total sample: 406

TABLE 2.A.3.

GENDER DISTRIBUTION

		YEAR 1							YEAR 2					
		Age							Age					
Sport	Gender	17	15	13	11	9	Total	Gender	18	16	14	12	10	Total
Football	M	12	25	28			65	M	10	23	25			58
Gymnastics	F	13	18	18	15	17	81	F	12	12	16	15	16	71
	M	7	10	10	6	5	38	M	6	6	7	5	4	28
Swimming	F	14	16	15	15		60	F	12	15	15	14		56
	M	10	14	15	15		54	M	10	12	12	14		48
Tennis	F	14	17	19	20	11	81	F	14	15	18	17	11	75
	M	12	15	18	19	10	74	M	11	14	16	19	10	70
	Total						453							406

There was a number of reasons why it was not possible to reach the proposed targets. For example, participation rates in some sports were very age-specific. The number of 16-year-old swimmers or gymnasts competing at a high level were few. In addition, the number of 16-year-olds signed on as apprentices by football clubs was only a small fraction of the numbers of 12-year-olds participating in the sport. Some coaches simply refused to take part. Yet despite all the possibilities as to why co-operation with the study was mixed, the concern was that perhaps there were not as many children taking part in intensive training as first thought. Until up-to-date registration is kept on participation rates it will be impossible to establish with any degree of certainty the numbers of children taking part in most sports.

2.A.2. Sampling

To avoid any systematic or personal bias in the selection of children for the study a random selection for each sport, birth year and gender group was achieved. Scrutiny of the lists of eligible children for the study revealed that in most cases there was a surplus over the planned group sizes. Where children declined to take part in the project, the surplus was used to reselect more candidates to top-up the group. A short questionnaire was sent to the children and parents who refused to take part, asking for estimates of hours trained and parental occupation. Comparing information from this group with data from families who agreed to take part established that there was no significant difference either in training time or social class. On this basis, TOYA had a representative sample of intensively-trained children.

2.A.3. Exclusion Criteria

Some athletes were at boarding school and thus living away from home. These were excluded from selection. There were several reasons for this: there were insufficient numbers of these children to create a special sub-group when distributed across age, gender and sport. It was also felt that these children were by definition exempt from many of the hypotheses under question in the study by virtue of their prolonged absences away from home.

2.A.4. Acceptance Rates

The acceptance rates, based on 576 initial approaches, for each of the sports are:

Football	Gymnastics	Swimming	Tennis
69%	88%	83%	75%

The reasons given by parents for not agreeing to their children taking part were many and varied. Some of the most common included:

a. No time because of sport or school work

b. Too far to travel

c. The child had given up sport or started work

2.A.5. Social class distribution of the sample

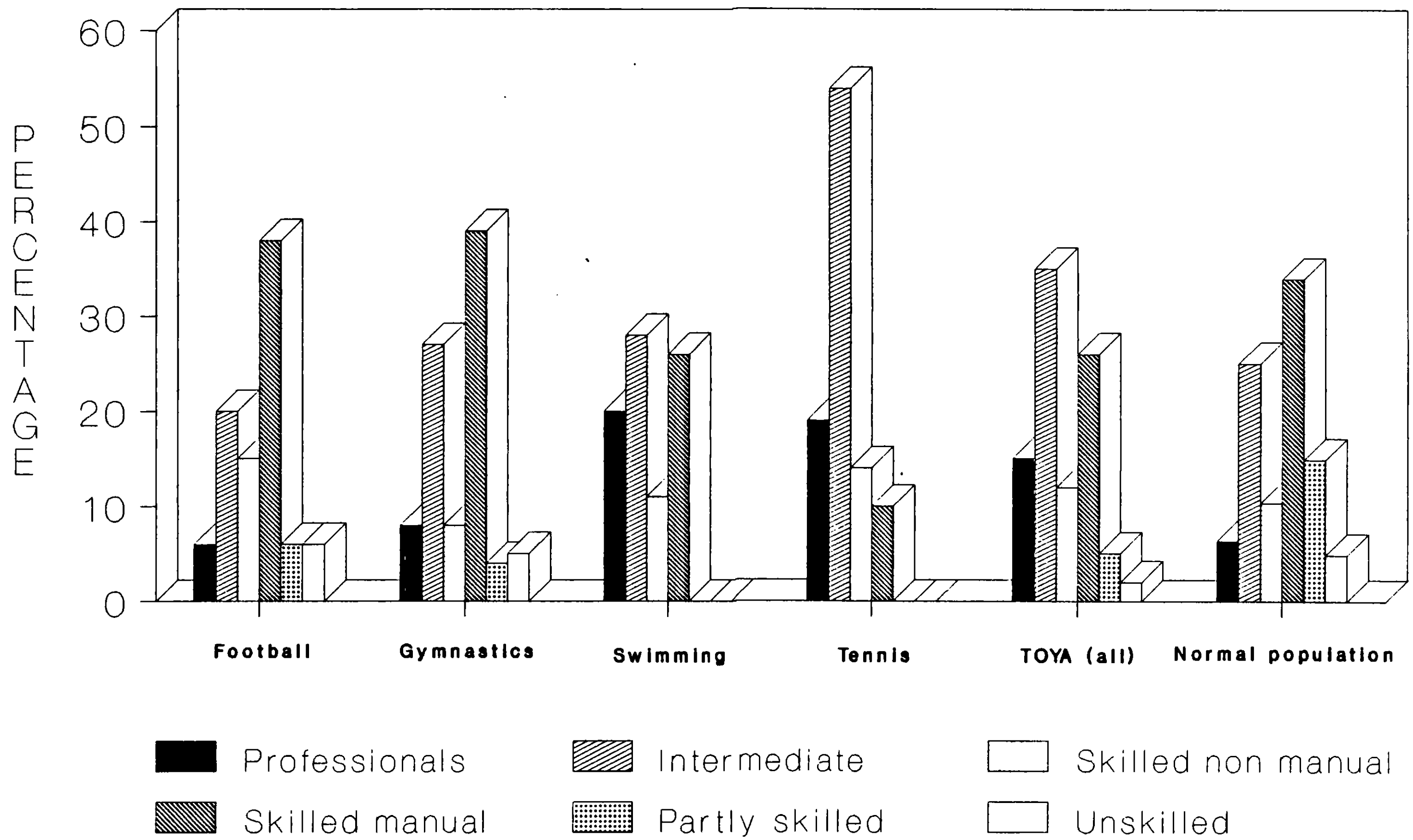
One of the most interesting findings was the social class distribution of the families taking part in the study. The lower socio-economic groups were significantly under-represented when compared to census data (Figure 2.A.1.) (Government Statistical Service, 1980). The reasons for this are various, and can be thus summarised:

1. Considerable financial support is required to enable children to participate in intensive-training routines.

2. Parental occupation has to be flexible to allow parents to have time off work to take their children training or to competitions.

3. Parents play a significant role in involving children in sport for health or safety reasons. It is more likely that the middle-classes see sport as having these attributes.

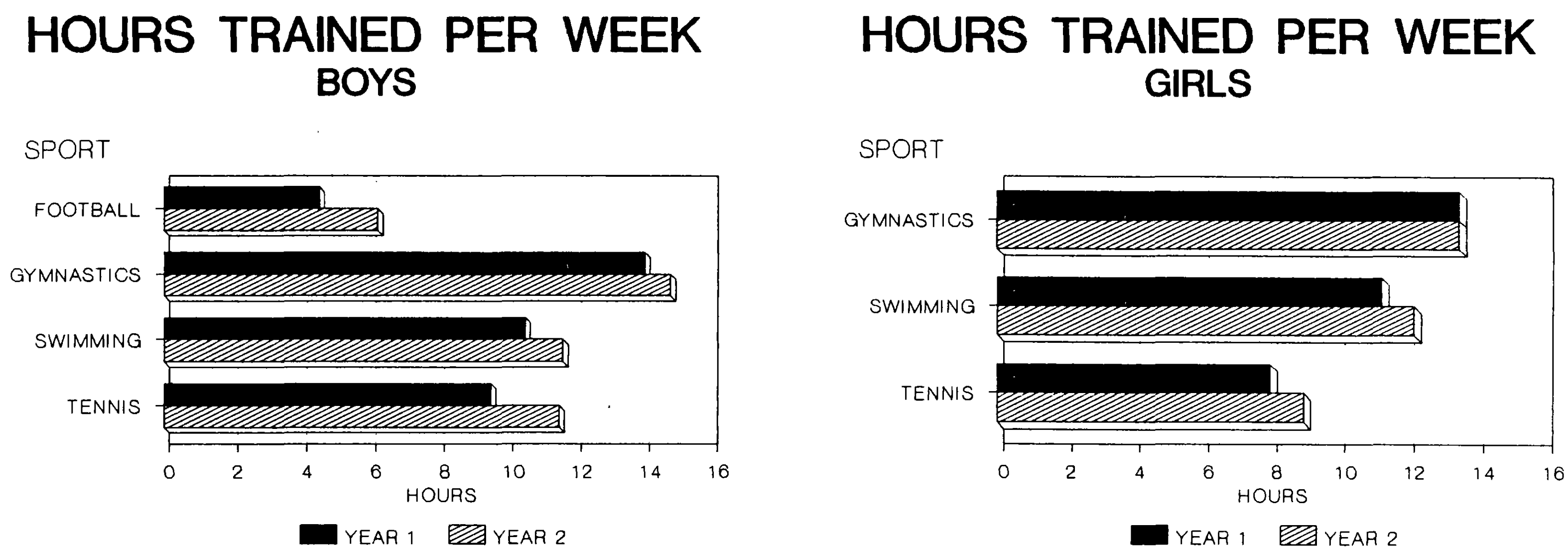
SOCIAL CLASSES



2.A.1. Social class distribution

2.A.6. Hours trained

Of the 453 children originally recruited not all were involved in intensive training. Moreover, there were substantial differences between the four sports regarding the proportion of children training at high level. The number of hours trained by age and sport in the two years of the study is shown in Figure 2.A.2 and Tables 2.A.4 to 2.A.10. The figures reported do not include the time it takes to get to and from the training facility, and the time spent competing. In young boys participating in sports like football, the latter may represent a significant proportion of the physical exercise performed as part of their sport.



2.A.2. Average number of hours trained per week

Football.

Footballers have only very modest levels of training between 12 and 15 years (cohorts 1975 and 1973), training an average of two to four hours per week (Table 2.A.4.). When they become apprentices attached to a professional football club, this figure may change dramatically.

TABLE 2.A.4.

Hours trained by male footballers in year 1 and 2

	YEAR 1						YEAR 2					
Birth Year	No	Age	(SD)	Min	Max	Mean	No	Age	(SD)	Min	Max	Mean
1975	28	12.8	(0.3)	0:00	8:30	2:18	26	13.9	(0.3)	0:00	9:00	4:10
1973	25	14.9	(0.4)	1:45	8:30	4:32	23	15.9	(0.4)	2:30	25:00	7:03
1971	12	16.9	(0.2)	0:00	24:30	9:12	10	18.0	(0.2)	4:00	34:00	10:39

Gymnastics.

Both male and female young gymnasts were the most intensively trained of the young athletes who entered the TOYA study. The minimum hours trained were close to the averages of the other sports, ranging from eight to 10 hours per week for males, and four to eight hours per week for females (Tables 2.A.5. and 2.A.6.).

TABLE 2.A.5.

Hours trained by male gymnasts in year 1 and 2

	YEAR 1					YEAR 2				
Birth Year	No	Age (SD)	Min	Max	Mean	No	Age (SD)	Min	Max	Mean
1979	5	9.2 (0.3)	2:30	14:00	7:33	4	10.3 (0.2)	2:30	17:00	7:41
1977	6	11.4 (0.3)	10:00	17:30	12:55	5	12.3 (0.3)	11:00	30:00	17:00
1975	10	13.1 (0.3)	8:30	22:30	14:25	7	14.1 (0.3)	11:45	30:00	17:42
1973	10	15.2 (0.4)	8:30	20:00	14:43	6	16.1 (0.2)	5:30	17:00	13:30
1971	7	17.1 (0.4)	8:30	29:00	17:20	6	17.9 (0.2)	5:00	27:30	15:07

TABLE 2.A.6.

Hours trained by female gymnasts in year 1 and 2

	YEAR 1					YEAR 2				
Birth Year	No	Age (SD)	Min	Max	Mean	No	Age (SD)	Min	Max	Mean
1979	17	9.4 (0.3)	5:00	21:00	11:27	16	10.4 (0.3)	4:30	23:30	11:33
1977	15	11.1 (0.3)	4:00	20:30	12:28	15	12.1 (0.3)	7:30	22:45	12:34
1975	18	13.0 (0.3)	6:30	23:00	13:29	16	14.0 (0.3)	6:45	24:15	13:55
1973	18	15.2 (0.3)	8:00	23:00	16:14	12	16.2 (0.5)	10:00	28:45	13:55
1971	13	17.1 (0.4)	4:00	21:00	13:25	12	18.2 (0.4)	5:30	20:00	13:21

Swimming.

Swimmers showed a similar training pattern to that shown by footballers and tennis players. In boys, the figure of one to three hours was the minimum hours trained per week, and indicated that a number of swimmers were not involved in intensive training (Tables 2.A.7. and 2.A.8.).

TABLE 2.A.7.

Hours trained by male swimmers in year 1 and 2

	YEAR 1						YEAR 2					
Birth Year	No	Age	(SD)	Min	Max	Mean	No	Age	(SD)	Min	Max	Mean
1977	15	11.1	(0.2)	2:30	15:45	7:17	14	12.2	(0.3)	4:00	17:45	11:22
1975	15	13.1	(0.3)	1:00	18:55	10:24	12	14.0	(0.3)	1:00	20:00	11:25
1973	14	15.0	(0.2)	3:30	22:30	13:02	12	16.0	(0.2)	3:30	22:30	12:59
1971	10	16.9	(0.2)	7:45	18:00	11:49	10	17.9	(0.2)	2:30	16:30	10:47

TABLE 2.A.8.

Hours trained by female swimmers in year 1 and 2

	YEAR 1						YEAR 2					
Birth Year	No	Age	(SD)	Min	Max	Mean	No	Age	(SD)	Min	Max	Mean
1977	15	11.1	(0.3)	3:00	13:45	7:27	14	12.1	(0.3)	2:45	20:45	11:17
1975	15	13.0	(0.3)	0:00	15:45	9:05	15	13.9	(0.3)	0:00	20:45	10:54
1973	16	15.7	(0.7)	6:15	22:30	13:22	15	16.1	(0.3)	0:00	22:30	13:35
1971	14	17.0	(0.4)	6:25	22:30	15:23	12	18.0	(0.4)	5:45	23:45	13:39

Tennis.

The data indicated that a number of male tennis-players played recreationally, the minimum figures for years one and two varying between two and three hours per week (Table 2.A.9.). Comparing the means for years one and two, there was a trend towards an increase in the number of hours trained for the 1979 to 1973 birth cohorts, while the 1971 birth group show a reduction.

TABLE 2.A.9.

Hours trained by male tennis players in year 1 and 2

	YEAR 1					YEAR 2				
Birth Year	No	Age (SD)	Min	Max	Mean	No	Age (SD)	Min	Max	Mean
1979	11	9.7 (0.3)	1:30	8:00	4:19	10	10.6 (0.3)	5:00	12:00	9:12
1977	19	11.0 (0.3)	4:00	11:00	7:08	19	12.0 (0.4)	2:30	18:30	8:43
1975	18	13.0 (0.3)	3:45	19:00	9:48	16	14.0 (0.2)	5:00	25:00	13:48
1973	15	14.9 (0.4)	2:45	18:30	8:47	14	15.9 (0.4)	2:45	19:20	11:43
1971	12	16.9 (0.3)	6:00	34:00	17:30	11	18.1 (0.4)	4:00	25:00	14:27

The data for females showed a more marked trend towards recreational involvement, the minimum hours trained ranging from one to three hours per week in all age groups except the 1975 cohort (Table 2.A.10.). This trend remained constant during the two years of the study.

TABLE 2.A.10.

Hours trained by female tennis players in year 1 and 2

	YEAR 1						YEAR 2					
Birth Year	No	Age	(SD)	Min	Max	Mean	No	Age	(SD)	Min	Max	Mean
1979	11	9.7	(0.3)	1:00	10:30	5:29	11	10.7	(0.3)	2:00	7:40	5:25
1977	20	11.1	(0.4)	1:00	16:15	5:22	17	12.2	(0.4)	3:00	24:30	8:05
1975	19	12.9	(0.4)	4:00	17:45	9:01	18	13.9	(0.4)	6:00	19:00	10:32
1973	17	14.9	(0.3)	3:00	29:45	10:16	15	16.1	(0.4)	3:00	13:30	7:44
1971	14	17.0	(0.4)	1:30	23:30	8:58	14	18.1	(0.4)	3:30	26:30	10:41

The data on hours trained per week indicated that, although perceived as training intensively, or expected to train intensively in the future by their coaches, this did not always follow. There was also a widespread variation in the actual amount of training performed by the subjects in the TOYA study.

The time take up in practising their sport was estimated for one year assuming the following:

1. a constant exposure to the sport throughout the year;

2. that the children involved in the TOYA study were taking only four weeks per year of rest from their

sport;

3. assuming at least one event per week for football and tennis, that at least 90 min per week were spent playing at competitive level. This amount of time was added to the time spent being exposed to the sport per year in order to calculate the rate of injuries per hour of exercise. This analysis and the results from it are shown in paragraph 3.A.a.2. (pp. 137-143).

2.A.7. Recruitment of controls

Several problems surrounded the recruitment of control children. These arose because of the failure to recruit classroom controls and the evident bias of the athlete population toward the higher socio-economic groups.

Because the projected number of controls was less than the size of the athlete population it was not possible to use a case-matched design. Instead a group-matched design containing children matched on certain salient characteristics were to act as a criterion group from which certain comparisons could be made.

Recruiting classroom controls failed because of lack of support of headteachers - too few schools agreed to co-operate. The acceptance rate was in the region of 32%. An alternative, peer nomination (a fairly common device often used in epidemiological research) was attempted. Reservations were expressed about this method as it was suspected that friends of young athletes would tend to be involved in sport themselves, thus invalidating them as controls. This proved to be the case; we were unable to recruit a sufficient number. The process of recruiting children from a number of primary and secondary schools in St Neots, a small town north of London, and the Greater London area was equally unsuccessful. This study does not therefore include data on a control population.

2.A.8. Attrition

At the end of the second year, 51 children (11%) had dropped out of the study. Given the longitudinal nature of the study, this rate is low. The rate of attrition is illustrated in Table 2.A.11.

TABLE 2.A.11.

Number of children who have withdrawn from the study

Cohort	Football	Gymnastics	Swimming	Tennis
1971	2	2	2	1
1973	2	10	4	4
1975	3	5	3	3
1977	-	1	2	5
1979	-	2	-	-
Total	7	20	11	13

2.A.9. Children who had retired from the sport

At the end of the second year, 11% of the children (36 girls, 14 boys) had retired from their sports, albeit still being involved in the study. Frequencies, stratified by gender, sport and age, are illustrated in Tables 2.A.12.

TABLE 2.A.12.

Number of children who had retired from their sport

	GIRLS			BOYS			
Cohort	G	S	T	F	G	S	T
1971	4	4	4	-	-	1	2
1973	6	4	-	1	3	1	3
1975	4	3	1	-	1	1	-
1977	2	3	-	-	1	-	-
1979	1	-	-	-	-	-	-
Total	17	14	5	1	5	3	5

F = Football G = Gymnastics S = Swimming T = Tennis

2.B. GROWTH AND DEVELOPMENT

2.B. GROWTH AND DEVELOPMENT

2.B.2. MATERIALS AND METHODS

Two trained measurers performed the following anthropometric measurements. All girls were measured by a female, and all boys were measured by the author. The inter- and intra-tester variability and reliability were tested regularly. Both inter- and intra-tester variability and reliability were such that the results for each measurement were reproduced within 5% of the initial value in at least 85% of cases. All anthropometric measurements were performed using a Harpenden Stadiometer, a Holtain anthropometer, a non-extensible CMS steel measuring-tape, a Holtain skinfold caliper, a Soehnle electronic scale accurate to 100 g, and a sitting-height box 50 cm tall. All measurements were performed according to Tanner & Whitehouse (1985a and 1985b).

Traditionally, anthropometric measurements are performed on the left side only. However, in view of the possible effect of an asymmetrical sport like tennis, skinfolds, limb circumferences and lengths were measured bilaterally.

2.B.2.1. Age

The system of decimal age has been used in this study (Tanner & Whitehouse, 1976).

2.B.2.2. Standing height

Standing height was measured without shoes using a Harpenden stadiometer. The child was standing with the heels and back in contact with the upright surface of the stadiometer. The head was held so that the child was looking straight forward with the lower borders of the eye sockets in the same horizontal plane as the external auditory meati. A right-angled counterweighted block was then slid down until its lower surface touched the child's head, and the stadiometer scale was read to the nearest completed millimetre (Tanner & Whitehouse, 1983a; Tanner & Whitehouse, 1983b). The measurement was performed twice, the results averaged, and this result used in all calculations.

2.B.2.3. <u>Sitting height and sub-ischial length length</u>

Sitting height (cephalo-ischiatic length) was taken using a Harpenden stadiometer. The child sat on a 50 cm high wooden box whose posterior surface lay against the anterior aspect of the upright portion of the stadiometer. The posterior aspect of the knees was directly over the edge of the box, and the feet hung down directly over the edge. The child's back was in contact with the upright surface of the stadiometer, and the thigh and buttock muscles were un-contracted. The head was held so that the child was looking straight forward with the lower borders of the eye sockets in the same horizontal plane as the external auditory meati. A right-angled counterweighted block was then slid down until its lower surface touched the child's head, and the stadiometer scale was read to the nearest completed mm. The measurement was performed twice, the results averaged, and the result used in all calculations. Sitting height was obtained by subtracting the height of the wooden box on which the child was sitting from the standing height. Sub-ischial leg length was obtained by subtracting this second value from standing height.

2.B.2.4. Weight

Weight was taken in running shorts and vests, wearing socks but no shoes. Weight was recorded to the last completed 0.1 kg (Tanner & Whitehouse, 1983a; Tanner & Whitehouse, 1983b).

2.B.2.5. Pubertal status

Stages of genitalia (penis) and breast development, and of pubic hair development were recorded using standard rating of 1 to 5 (Tanner, 1962), and stages of axillary hair were recorded using standard rating of 1 to 3 (Tanner, 1962).

2.B.2.6. **Upper arm circumference**

Upper arm circumference was taken bilaterally with the child's arm hanging relaxed and slightly abducted. The mid-distance between the lateral end of the acromion, proximally, and tip of the olecranon, distally, was marked on the skin, and the tape applied at this level. Gentle pressure was applied, and the upper arm circumference was read to the nearest completed mm.

2.B.2.7. **Skinfolds**

All skinfolds were measured bilaterally using a Harpenden skinfold caliper designed to exert a constant pressure of 10 gm/cm^{-2} over its entire opening range. The skinfolds were measured by picking up a fold of skin and subcutaneous tissue between the left thumb and forefinger initially placed about 2 cm apart on the skin, and pinching it away from the underlying muscle. The left hand maintained the pinch throughout the measurement, while the right hand relaxed its grip on the handle of the caliper, so that its jaws could exert their full pressure. Measurements were read two to three seconds after the caliper was applied (Tanner & Whitehouse, 1985a; Tanner & Whitehouse, 1985b).

2.B.2.7.1. **Triceps skinfold**

The triceps skinfold was measured on the vertical fold on the mid-posterior line midway between the lateral end of the acromion and the tip of the olecranon process while the elbow was slightly flexed and the upper arm was extended vertically downwards.

2.B.2.7.2. **Biceps skinfold**

The biceps skinfold was measured on the anterior aspect of the arm. The mid-distance between the lateral end of the acromion, proximally, and tip of the olecranon, distally, was marked on the skin. The skinfold-caliper jaws were applied at this level while the elbow was slightly flexed and the upper arm was extended vertically downwards.

2.B.2.7.3. **Subscapular skinfold**

The subscapular skinfold was picked up just below the angle of the scapula with the fold either on a vertical line or slightly inclined, in the natural cleavage line of the skin.

2.B.2.7.4. Suprailiac skinfold

The suprailiac skinfold was picked up 1cm above and 2 cm medial to the superior anterior iliac spine with the fold slightly inclined, in the natural cleavage line of the skin.

2.B.2.9. Muscle and bone area of the upper arm

Muscle and bone area of the upper arm (MBA) was calculated using the de Koning et al. (1986) equation:

$$MBA = pi \left(\frac{CA}{2\ pi} - \frac{BA + TA}{4} \right)^2$$

where CA = upper arm circumference in cm, BA = biceps skinfold in cm, and TA = triceps skinfold in cm.

2.C. THE TREATMENT OF DATA

2.C. THE TREATMENT OF DATA

For all the procedures described in this thesis, a pilot study on 32 children was performed four months before the beginning of the main study. All the flexibility and strength measurements, the medical examination, and the injuries questionnaire were administered by the author in all but 13 children in the first year and 19 children in the second year of the study. Anthropometry and pubertal staging were carried out by the author in all boys, except in six boys in year one, and eight in year two. All girls were measured and puberty evaluated by a trained female anthropometrist, who also measured the boys when the author was absent.

2.C.1. <u>THE 'PHILOSOPHY' OF THE TOYA STUDY</u>

The longitudinal method consists of measuring the same individual at regular intervals over a period of time. The basic unit of analysis is the cohort, i.e. a sub-population sharing common characteristics, in this case exposure to high level sport. A typical longitudinal study uses a single cohort, monitoring the changes occurring within this population over the research period. A mixed-longitudinal study uses linked longitudinal cohorts, and the sub-population is thus represented by more than one sample group. When compared to single cohort studies, it is evident that this method is less sensitive to the problem of diminishing sample size. As each developmental period is represented by its own cohort, the study does not have to rely on just one group passing through the successive stages of pubertal development.

2.C.1. **THE TREATMENT OF DATA**

All the data were stored in R:Base on an IBM-compatible PC. All entered data were randomly checked four times for accuracy comparing them with the hard data: the percentage of error was less than 2% and, after the fourth check, the data were considered to be clean. The data were analysed using the SAS (Joyner, 1985) and the Systat (Leland, 1988) statistical packages, installed on IBM compatible personal computers.

Descriptive statistical analysis was carried out, and potential intra- and inter-cohort variations were tested for significance using analysis of variance (ANOVA) and analysis of covariance (ANCOVA), taking into account the effects of various covariates. When linear regression analysis was used to test the various relationships, this is specified in the text. Due to the number of primary analyses, the 0.03 level of significance was used to define a significant difference in order to minimise the possibility of a Type I interpretative error.

For simplicity, many graphs were drawn using only average data. However, the data were always plotted using average ± one standard deviation. The data on descriptive statistics on the measures considered are given in the Appendixes 7 and 8 (flexibility and strength data), and the individual data are given in

Appendices 3 and to 5. The data on injuries analysis are given in Appendix 6.

The flexibility and strength data were fitted with a third order polynomial which minimised the residual sum of squares (Leland, 1988).

Although it has been common practice to express muscular performance as a ratio to body weight and cross sectional area of the muscle tested (Maughan, 1984; Jones and Rutherford, 1987), Tanner (1949) has shown that this approach, fallacious in itself, is misleading. Moreover, ratios are often treated as if they were means for single measures to compare groups. This is equally misleading (Tanner, 1964), and other ways of describing the relationship between variables should be employed (Tanner, 1964). Analysis of covariance is one of these methods (Joyner, 1985; Leland, 1988), and has been used in this study.

2.D. INJURIES

2.D. INJURIES

In this study an injury was classified as a musculo-skeletal problem requiring reduction or interruption of the sporting activity for any length of time, possibly following any sort of professional advice. Injuries were classified as acute or overuse. An acute injury was an injury arising because the musculo-skeletal system was exposed to a single episode of stress exceeding its level of tolerance. An overuse injury, instead, arose because the limit of tolerance of the musculo-skeletal system had been exceeded by repetitive submaximal loading (Nilsson, 1982). In other words, acute injuries were due to a single remembered event, whilst in overuse injuries no single event could be identified.

Injuries were investigated retrospectively using the questionnaire enclosed in Appendix 1. The questionnaire was administered personally by the author to both the child and the accompanying parent/guardian at each visit. Each child and his/her parent were questioned about the latest injury suffered in a period of 12 months prior to the visit to the TOYA Study. They were subsequently asked to work backwards in recalling other injurious events.

Injuries were classified according to their occurrence as training-, competition- or causes-other-than-sports induced. Their nature was divided into acute and overuse, and the musculo-skeletal component involved was recorded. The children were also asked whether:

1. they had consulted a professional, and, if so, how much time was spent between the injury and the actual treatment, and what the treatment was;

2. whether any payment was made, and if this had happened, if this was subsidised in any way;

3. whether time off sport had been taken, and, if so, for how long.

2.E. FLEXIBILITY

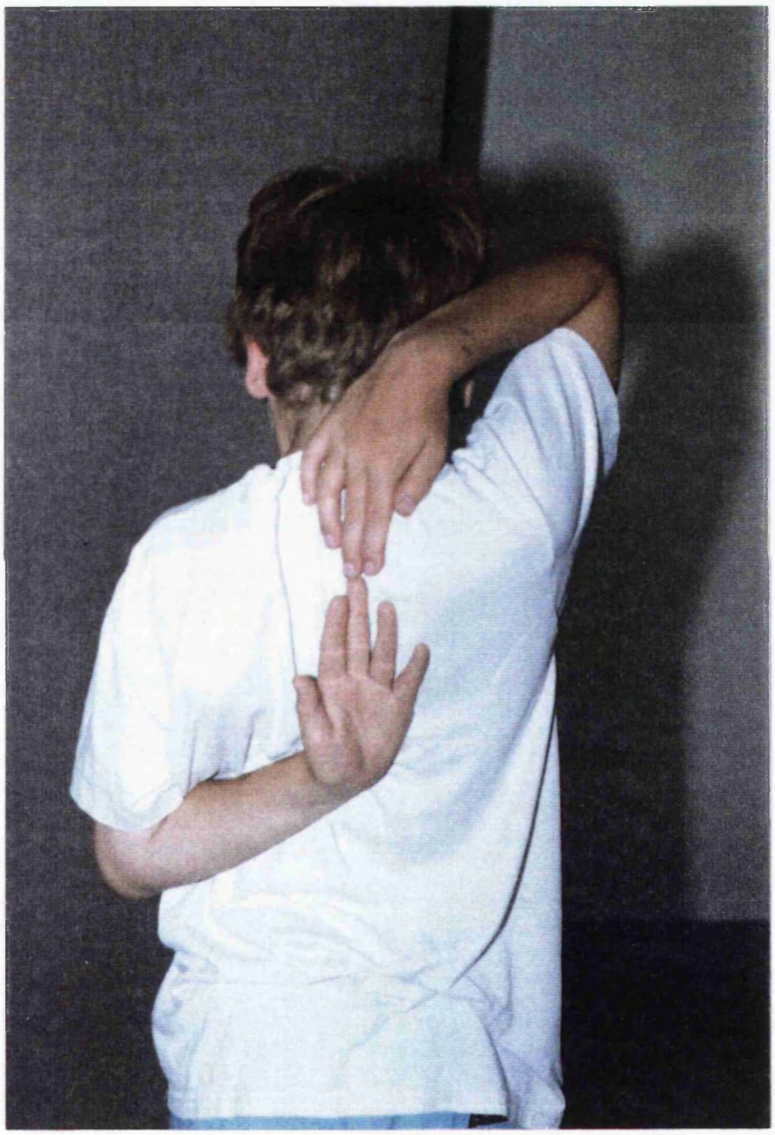
2.E. FLEXIBILITY

Four tests were used to measure the flexibility of the upper limb, lumbar spine and lower limb. All the tests were performed after a brief period of warm up, consisting of gentle stretching exercises. All the tests were demonstrated to the young athletes several times, and the children performed the tests only when they were confident. The tests were performed in the sequence described below, and the subjects were verbally encouraged to perform at their best.

2.E.2.1. Flexibility of the upper limb and gleno-humeral joint

Elbow and gleno-humeral joint flexibility was evaluated bilaterally using the 'cross behind the shoulders' test (Koch et al., 1988). In this test, one shoulder is first extended in the sagittal plane with the elbow flexed and the hand facing away from the trunk, resulting in a movement of the hand towards the head. The contralateral shoulder is then flexed in the sagittal plane with the elbow flexed and the palm of the hand facing towards the trunk, resulting in movement of the hand towards the feet. The hands are then approximated and overlapped, if possible, and the distance in mm between the tips of the most prominent fingers (generally the middle fingers) is recorded in mm as positive if the hands are overlapped, zero if they just touch, and negative if they do not touch at all (Figure 2.E.1.).

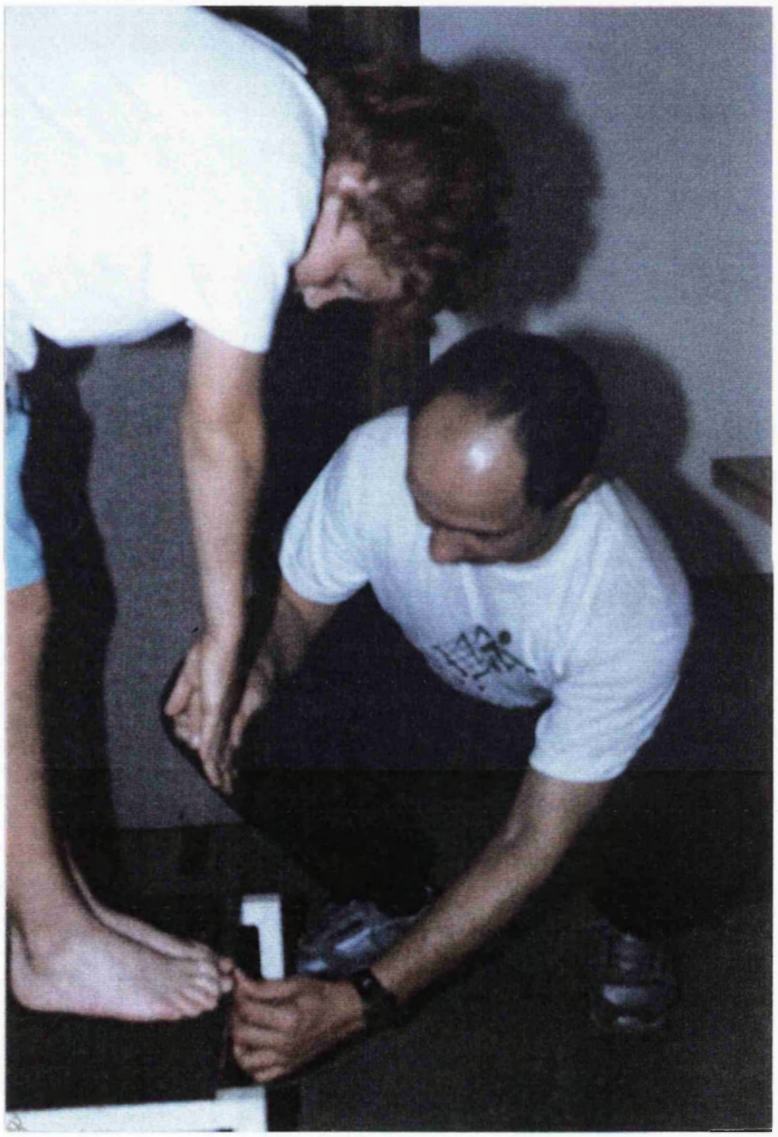
Figure 2.E.1 Method used to measure the flexibility of the upper limb and gleno-humeral joint



2.E.2.2. Flexibility of the lumbar spine and hamstrings

The subjects stood on a step 22 cm high. If the athlete could touch the floor on the 22 cm step, then he or she were asked to stand on a stool 50 cm high. The subject was then asked to bend forward, and to try and touch the tips of his/her feet with the tips of his/her fingers, with the feet together and without flexion of the knees. The distance in millimetres between the tips of the most prominent left finger (generally the middle finger) was recorded in millimetres as positive if the hands could be overlapped on the superior surface of the left hallux nail, zero if they just touched them, and negative if they did not touch them at all (Figure 2.E.2.).

Figure 2.E.2 Method used to measure the flexibility of lumbar spine and hamstrings



2.E.2.3. Flexibility of the hip , adductor muscles and posterior muscle complex of the thigh

This was measured using two tests:

A. sagittal splits (Wiklander & Lysholm, 1987);

B. frontal splits (Wiklander & Lysholm, 1987).

The subject wore socks in order to reduce friction against the floor and was allowed to hold on with one or both hands to an examination couch if they so wished. The feet were slowly separated as far as possible.

In Test A the distance between the medial ends of the calcanei was measured in centimetres. Both feet were kept parallel to the axis of bilateral symmetry of the body (Figure 2.E.3.).

In Test B measurements were performed with both the right and the left foot as leading foot. The distance in centimetres between the contact area of the calcaneus of the anterior foot and the medial end of the calcaneus of the posterior foot was measured. The back foot was kept perpendicular to the axis of bilateral symmetry of the body, the front foot parallel to it (Figure 2.E.4.).

Figure 2.E.3 Method used to measure the flexibility of the hip , aductor muscles and posterior muscles of the thigh: sagittal splits

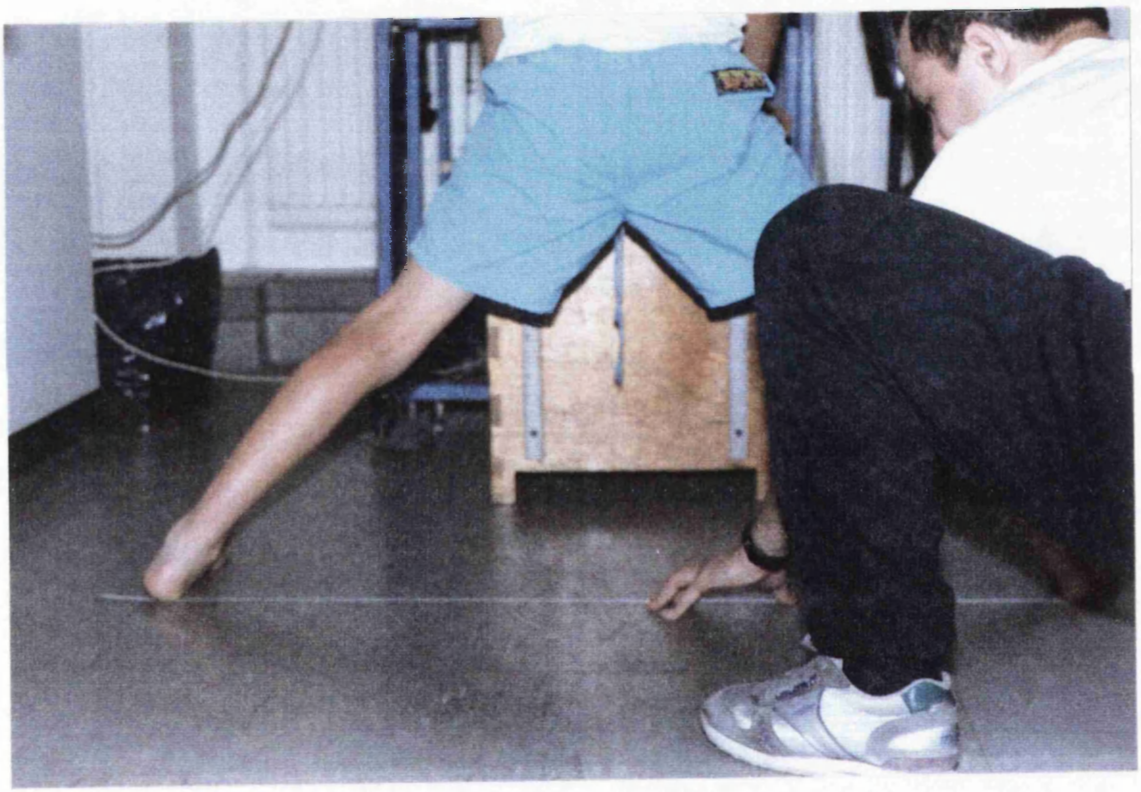
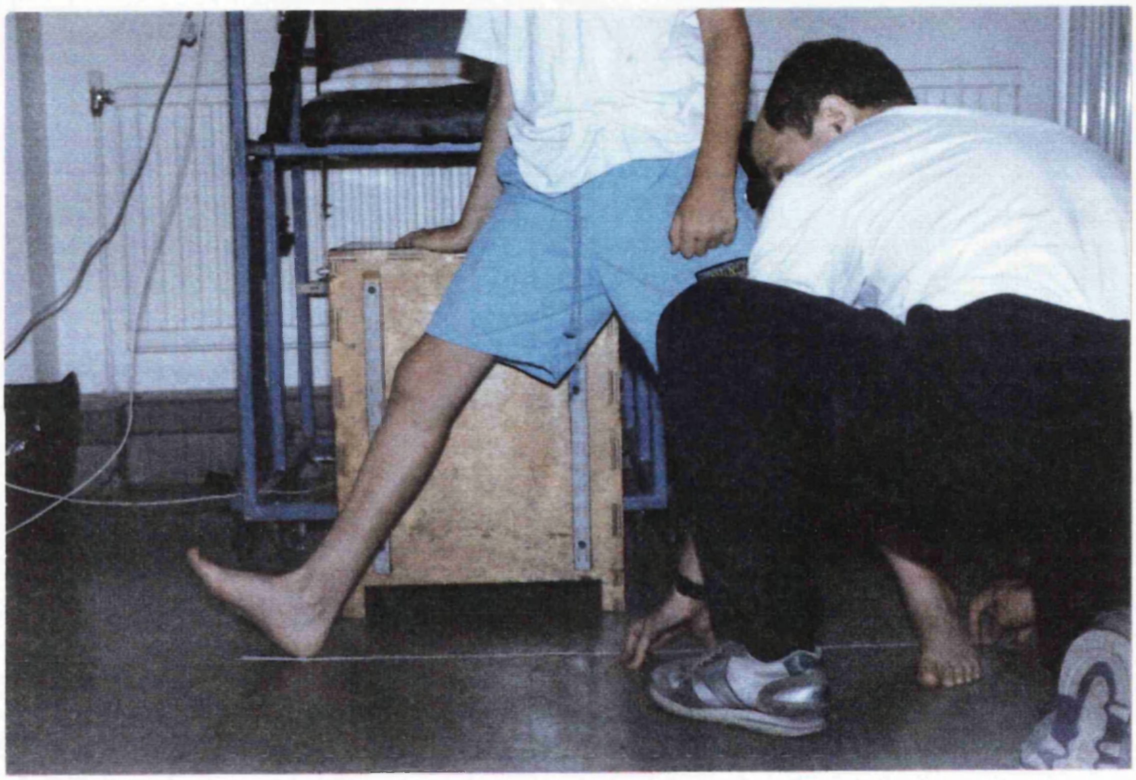


Figure 2.E.4 Method used to measure the flexibility of the hip , aductor muscles and posterior muscles of the thigh: frontal splits



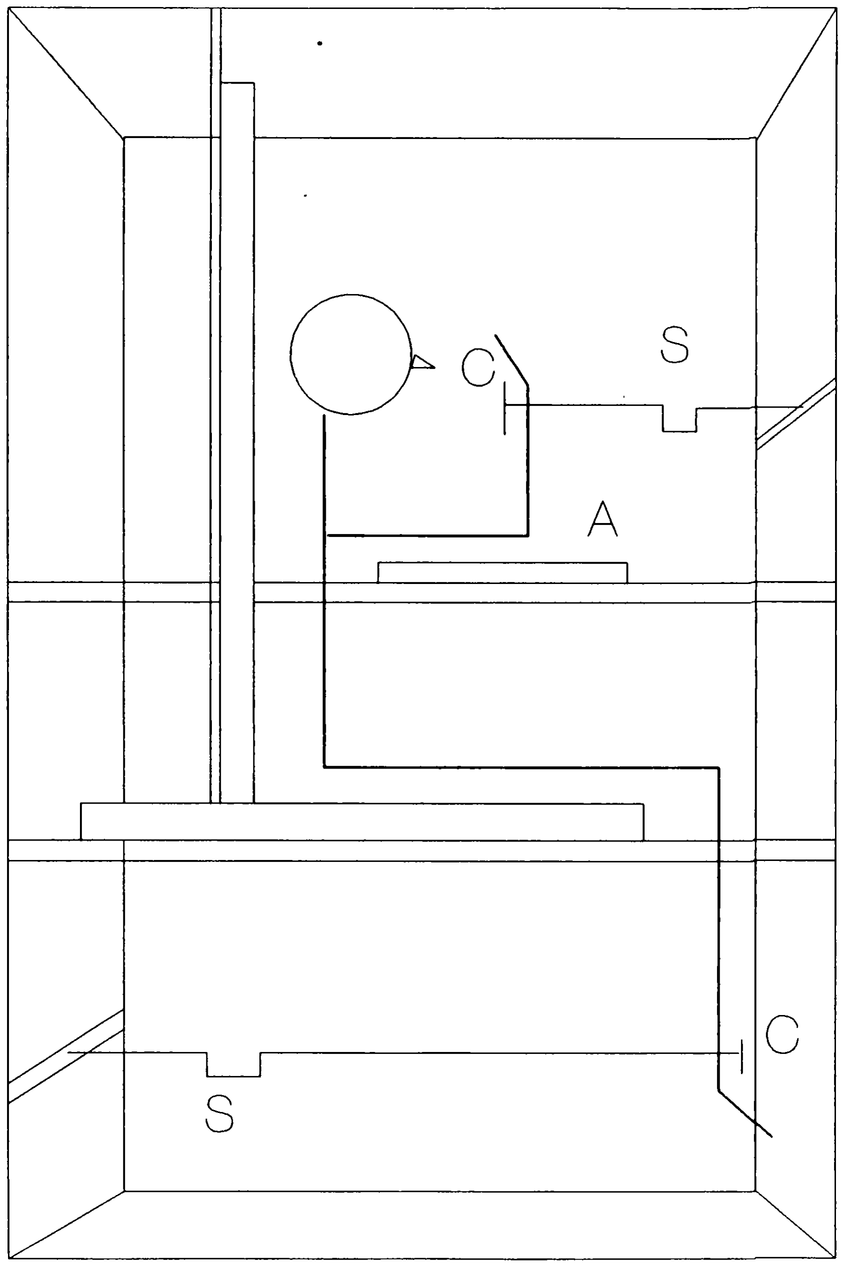
2.F. STRENGTH

2.F. STRENGTH

The muscle groups tested in this study were the **elbow flexors**, composed of the muscles biceps brachii, brachialis, brachioradialis, pronator teres and extensor carpi ulnaris and the **knee extensors**, composed of the muscles vastus lateralis, vastus intermedius, vastus medialis and rectus femoris, constituting the quadriceps femoris (Last, 1984). While being aware of the different components generating force when the elbow is flexed and the knee extended, for convenience the terms 'elbow flexor strength' and 'bicipital or biceps strength', and 'knee extensor strength' and 'quadricipital or quadriceps strength' will be used interchangeably.

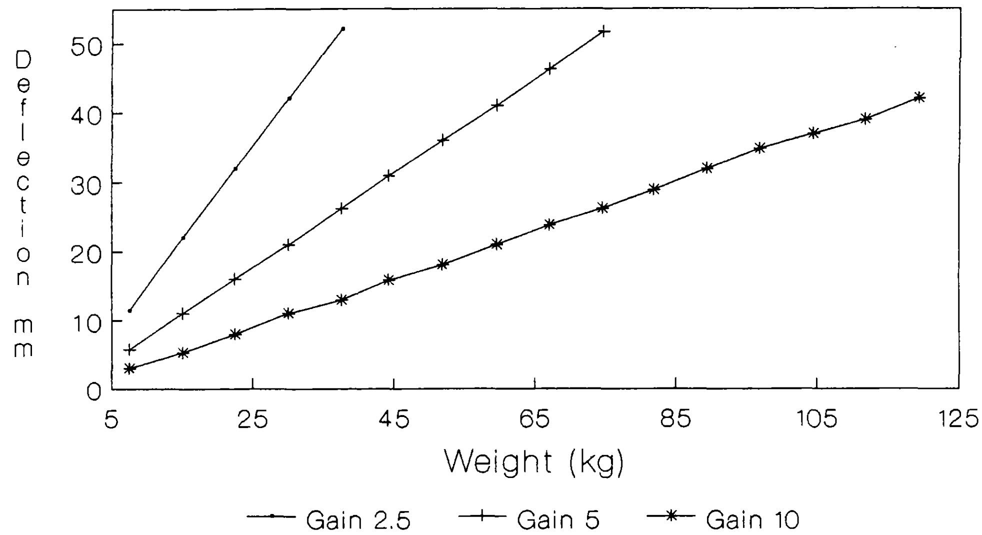
Maximum isometric voluntary contraction (MIVC) strength was measured bilaterally using a custom-made chair (Davies et al., 1988) (Figure 2.F.1.). A metal bar was attached to the front and another to the back of the chair to accommodate a compact portable gauge consisting of two silicon strain gauges (Kulite Sensors Ltd, Type DDP.350.500) bonded to either side of the horizontal portion of a U-shaped piece of aluminium alloy forming two arms of a Wheatstone bridge (Jones & Parker, 1989). The gauges were incorporated into an inextensible link between a cuff around the limb to be tested and a fixed point about which the link could swivel. In this way, the gauge was always in the direct line of action of the force applied to it. When energised with 5V, and the output amplified on an amplifier-recorder (Model 8818 2202 09, Series 552, Gould Manufacturers, France) the gauges gave a linear response to force within a range from 73.5 to 1200 Newtons (Jones & Parker, 1989). The height of the anterior and posterior bars was adjusted for each child so that the gauges were coplanar with an horizontal plane passing through the wrist joint and the ankle joint. The apparatus was calibrated at least every week by suspending known weights, ranging from 7.5 to 119.6 kg, from the strain gauge, and reading the deflection shown by the Gould amplifier-recorder (Figure 2.F.2.).

Muscular strength was determined by reading the deflection produced, relating it to the gain at which the measurement had been done, and multiplying the value thus obtained by 9.8 to express it in Newtons.



2.F.1. The apparatus used to measure isometric strength

STRAIN GAUGE
CALIBRATION



2.F.2. A typical strain gauge calibration response

2.F.2.1. Elbow flexor muscles

The child's arms were resting on a shelf, and the chair back and shelf were adjusted so that the subject was sitting upright with the back supported, and the shoulder and elbow joint at 903. The forearm was kept in full supination, and the strain gauge was connected to the wrist through a padded protective splint. Lap and chest straps prevented forward movement of the subject during the contraction.

2.F.2.2. Knee extensor muscles

MIVC force of the knee extensors was measured using the apparatus described above. The strain gauge was attached to the back of the chair. During the measurement, the subject's arms were kept crossed in front of the chest. Elevation of the hips was prevented by lap and chest straps.

2.F.2.3. Testing procedure

The author was responsible for all measurements. Each child was introduced to the procedure, and then asked to produce four maximal MIVC for each limb. Each child performed the testing procedure in one of the two following orders, at random:

a. right arm - left arm - right leg - left leg;

or

b. right leg - left leg - right arm - left arm.

The four attempts were recorded and measured, and the highest was used in all the work described in this thesis.

This method of MIVC recording has shown good reliability and reproducibility (Parker, 1989), and there are few problems in fully recruiting the quadriceps or the elbow flexors (Rutherford et al., 1986).

The differences between the four trials were less than 5% in a random sample of 10 children of each sex per each age group per each year, and showed no significant fatiguing or learning effects between the first and the last contraction (Tables 2.F.1. to 2.F.4.).

TABLE 2.F.1.

Variation for the four maximum voluntary isometric contractions

of the elbow flexors and knee extensors

E = elbow flexors   K = knee extensors

FEMALE

RIGHT HAND SIDE (%)

Subjects age	1 vs 2		2 vs 3		3 vs 4		1 vs 3		2 vs 4		1 vs 4	
	E	K	E	K	E	K	E	K	E	K	E	K
9	0.5	1.7	-1.5	3.6	0.9	3	-1	-3.2	1.4	0.9	2.6	1.2
10	2.7	3.1	1.5	2.7	1.4	3.6	2.3	3	-1.5	2.5	1.6	4.2
11	1.2	3.1	-1.8	3.2	2.6	-0.9	3.4	-1.6	2.5	1.1	-2.1	-1.8
12	1.3	-2.4	3.6	1.5	-2	2.9	1.7	-3	3.2	2.4	-2	3.8
13	2.1	1.3	-3.3	1.4	1.8	1.1	-1.3	3.8	2.2	3.1	-1.7	-2.3
14	1.6	2.4	-2.7	1.9	3	2.6	-3.2	3	2.5	3.4	2.8	-2.6
15	-1.4	3.6	1.5	-3.1	-1.8	-2.2	1.3	3.3	1.7	3.5	1.5	-2.9
16	-3.2	1	1.3	1.7	-1.5	0.9	3	-1	3.1	2.5	-2.2	1.6
17	3.1	3.7	-2.3	2.5	1.5	2.5	2.3	2.5	2.9	1.6	3.6	4.4
18	2.2	-0.8	3.7	1.5	-2.3	1.9	3.2	1.6	3.2	1.1	2.4	3.9
19	2.5	-3	1.5	-1.2	3.4	2.8	1.7	-3.6	1.2	2.8	2.2	1.6

TABLE 2.F.2.

Variation for the four maximum voluntary isometric contractions

of the elbow flexors and knee extensors

E = elbow flexors   K = knee extensors

FEMALE

LEFT HAND SIDE (%)

Subjects	Age	1 vs 2		2 vs 3		3 vs 4		1 vs 3		2 vs 4		1 vs 4	
		E	K	E	K	E	K	E	K	E	K	E	K
	9	2.5	1	-1.6	3.3	1.9	3.5	1.1	-3	1.4	0.7	3.1	-2.6
	10	1.1	4.6	2.7	2.3	-1.5	2	2.7	3.2	1.5	2.7	2.2	1.9
	11	2.6	-1.9	3.5	-1.6	2.5	1.1	1.3	3.1	-1.8	3.2	1.7	2.6
	12	2.4	3.6	1.5	-2	3.2	2.4	2.9	1.7	-3	1.3	3.2	-1.5
	13	1	-3.3	1.5	1.2	2.2	3.5	1.1	-1.3	2.8	2	2	3.1
	14	2.6	-2.8	-0.9	3.7	1.7	3.5	2.2	1.3	3.3	1.7	1.3	3.4
	15	1.3	-2.4	3.6	1.5	-2	2.3	3.1	1.2	3.1	-1.8	1.6	-1.8
	16	2.1	1.3	-3.3	1.4	1.8	1.6	3.7	2.3	3.1	1.6	1.6	-2.7
	17	1.6	2.4	-2.7	1.9	3.2	2.4	-1.8	4	1.6	-2.3	-2.5	-1.3
	18	1.4	3.6	1.2	-3.1	1.8	1.3	3.6	1	-1.3	2.4	3.9	2.2
	19	3.2	1	1.3	1.7	-1.5	2.6	1.6	1.3	1.9	3.4	2.4	4.6

TABLE 2.F.3.

Variation for the four maximum voluntary isometric contractions

of the elbow flexors and knee extensors

E = elbow flexors   K = knee extensors

MALE

RIGHT HAND SIDE (%)

Subjects	Age	1 vs 2		2 vs 3		3 vs 4		1 vs 3		2 vs 4		1 vs 4	
		E	K	E	K	E	K	E	K	E	K	E	K
	9	-2	1.3	3.1	1.8	2.1	2.7	-0.9	3	1.7	3.5	1	3.3
	10	2.6	-0.6	3	-1.4	3.6	1.5	3.3	1.6	2.7	4.1	2.7	2.3
	11	0.9	3	-1	-3.2	1.4	0.3	1.9	-1.5	3.8	4.5	2	-1.6
	12	1.1	3.7	-2.3	3	1.5	2.5	3	1.5	2.2	2.6	1	-2.2
	13	2.6	-0.5	3.8	-1.6	2.3	1.1	3.1	-1.5	3.2	1.1	2	-1.9
	14	2.4	3.3	1.5	-1	3.2	2.9	1.7	-3	1.2	0.8	3.1	4
	15	0.3	1.7	-1.5	3.5	0.9	3	-1	-3.2	1.4	0.3	2.9	3.3
	16	2.5	3	1.5	2.7	1.1	3.7	-2.3	3	1.5	2.5	3	-2.1
	17	1.1	3.1	-1.5	3.2	-2.6	-0.5	3.4	-1.6	2.3	1.1	-1	2.1
	18	2.9	1.7	-3	1.5	2.4	3.2	1.5	-4	3.2	2.9	3	-0.9
	19	1.3	-1.9	3	2.1	1.5	-3.3	1.4	0.8	2.6	3.1	1.2	2.3

TABLE 2.F.4.

Variation for the four maximum voluntary isometric contractions

of the elbow flexors and knee extensors

E = elbow flexors   K = knee extensors

MALE

LEFT HAND SIDE (%)

Subjects	Age	1 vs 2		2 vs 3		3 vs 4		1 vs 3		2 vs 4		1 vs 4	
		E	K	E	K	E	K	E	K	E	K	E	K
	9	0.5	1.7	-1.5	3.6	0.9	3	-1	-3.2	1.4	0.9	3.3	0.9
	10	2.7	3.1	1.5	2.7	1.4	3.6	2.3	3	-1.5	2.5	2.3	3.3
	11	1	3.1	-1.8	3.2	2.6	-0.9	3.4	-1.6	2.5	1.1	1.6	1.9
	12	2.9	1.7	-3	1.3	-2.4	3.6	1.5	-2	3.2	2.4	2	-3.1
	13	1.1	-1.3	3.8	2.1	1.3	-3.3	1.4	1.8	2.2	3.1	1.2	3.6
	14	-2.2	1.3	3.3	1.6	2.4	-2.7	-0.9	3	1.7	3.5	3.6	-1.7
	15	2.6	-0.6	3	-1.4	3.6	1.5	-3.1	-1.8	2.5	3.4	1.1	2
	16	0.9	3	-1	-3.2	1	1.3	1.7	-1.5	3.1	2.5	3.7	-2.3
	17	3.1	3.7	-2.3	2.5	1.5	2.5	2.3	2.5	2.9	1.6	0.8	4
	18	2.2	-0.8	3.7	1.5	-2.3	1.9	3.2	1.6	3.2	1.1	3	-1.5
	19	2.5	-3	1.5	-1.2	3.4	2.8	1.7	-3.6	1.2	2.8	2.2	1.4

2.F.2.4. The problem of lever ratio in strength measurements

The force exerted by a muscle or muscle group depends on the lever system through which the muscle or muscle group acts. When measuring strength at a point distal to the insertion of the muscle or muscle group tested (in the present study the ankle and the wrist), the force generated depends on the ratio between the distance **p** (i.e. the distance from the centre of rotation of the joint to the line of action of the force) and the distance **d** (i.e. the distance between the centre of rotation of the joint and the point at which the force is measured) (Parker, 1989). So:

Force generated by a
muscle or muscle group = Force measured x p/d

The estimation of the lever ratio is complicated. It would require knowing the exact location of the attachment and insertion of the muscles contributing to the flexion of the elbow and the extension of the knee. This was not feasible in this study.

Previous limited studies suggest that the p to d ratio remains fairly constant throughout the growth process in the tibia, while the ratio decreases in the forearm (Parker, 1989). For practical purposes, the p/d ratio was not measured in the athletes taking part in this study, and the ratio was assumed to remain constant at all ages throughout the duration of the work reported in this thesis.

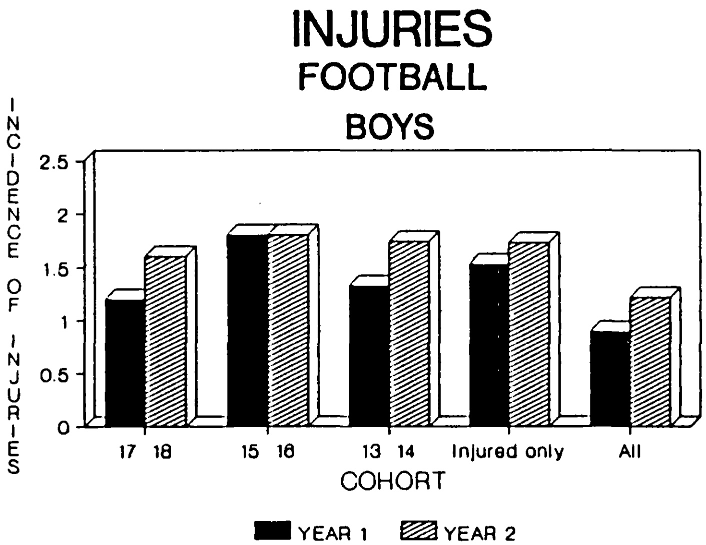
CHAPTER 3: RESULTS AND DISCUSSION

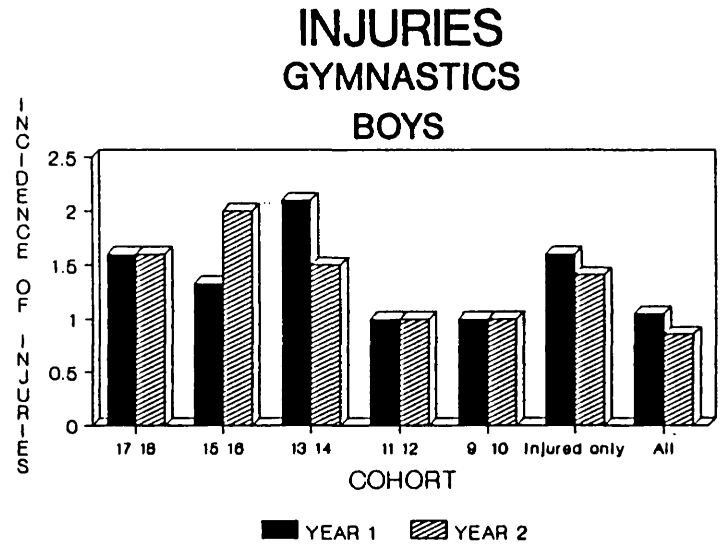
3.A. INJURIES: RESULTS

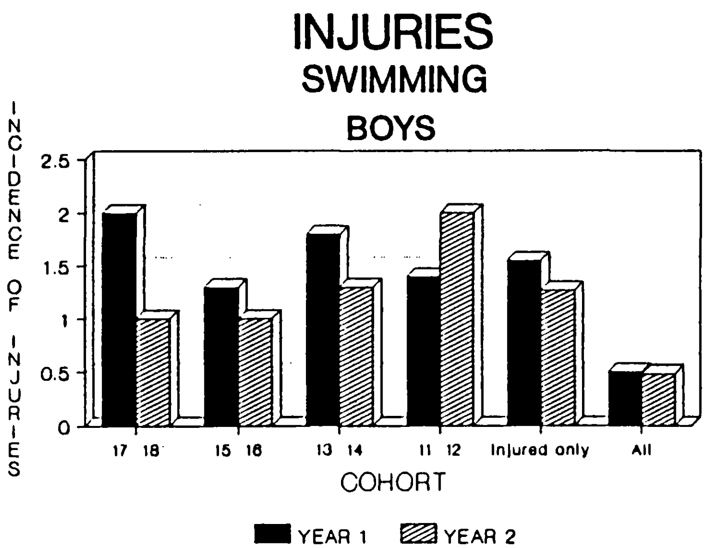
The absolute total number of injuries remained constant at 229 in year 1 to 226 in year 2. Given the number of children taking part to the study, 453 in year 1 and 406 on year 2, the injury rate increased marginally from 0.50 to 0.55 injuries per year per child, a difference which was not statistically significant. Injury rate remained constant at about one injury per injured child. The number of acute and overuse injuries remained fairly constant, at a rate of 0.4 and 0.44 for acute injuries, and 0.16 and 0.18 for overuse injuries, respectively for year 1 and year 2.

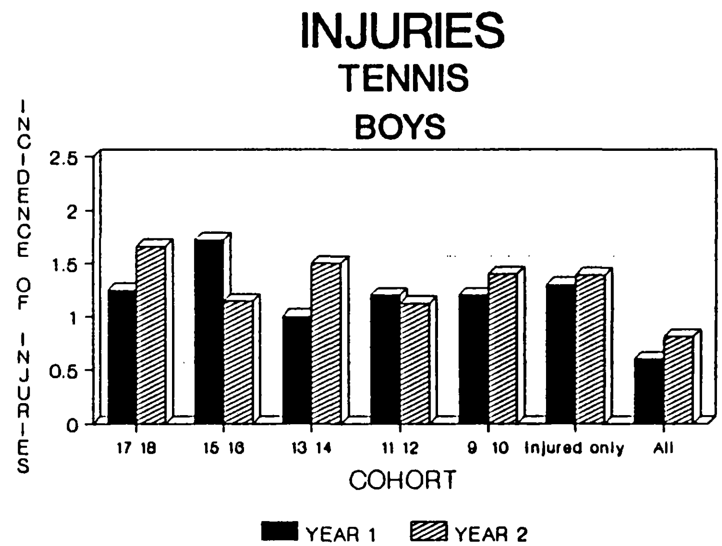
The actual number of acute and overuse injuries varied between the four sports and the genders. This probably reflected the different nature of the four sports, and the different degree of involvement that each sports requires.

The rate of incidence of injuries is shown in Figure 3.A.1. for boys and Figure 3.A.2. for girls. In the following figures depicting the incidence of injuries, acute and overuse injuries have been combined, and the incidence has been calculated. The 'Injured only' columns depict only those children injured at least once. The incidence shown in the last column, marked 'All', considers the whole sample, including the children not injured.

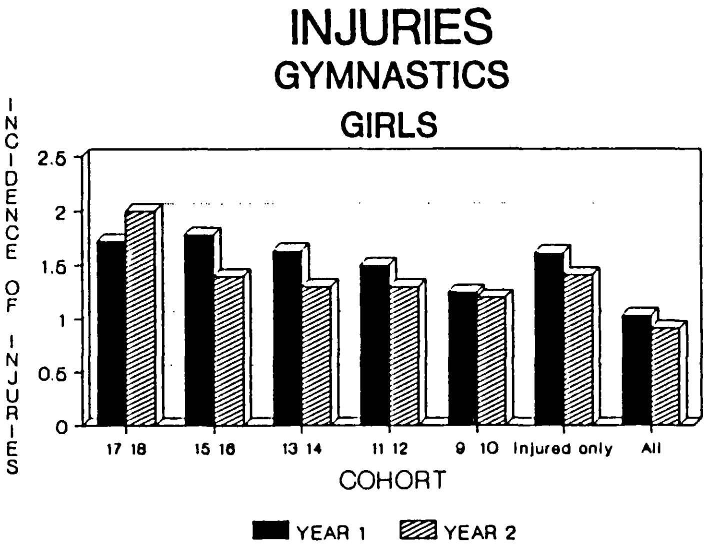


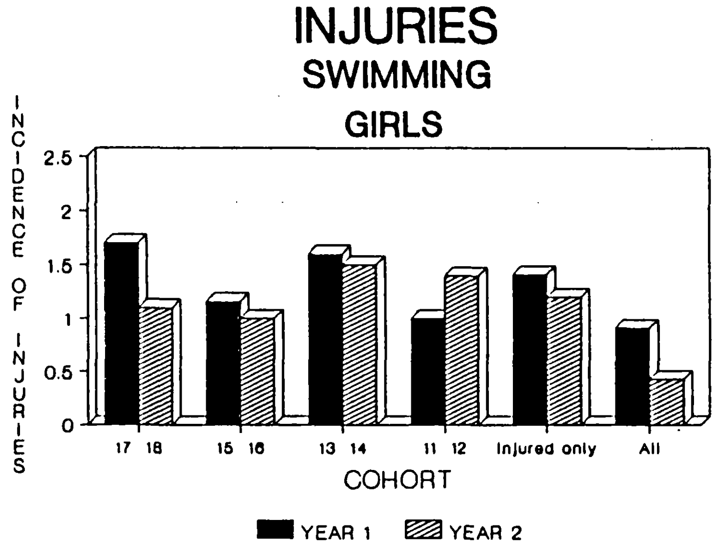


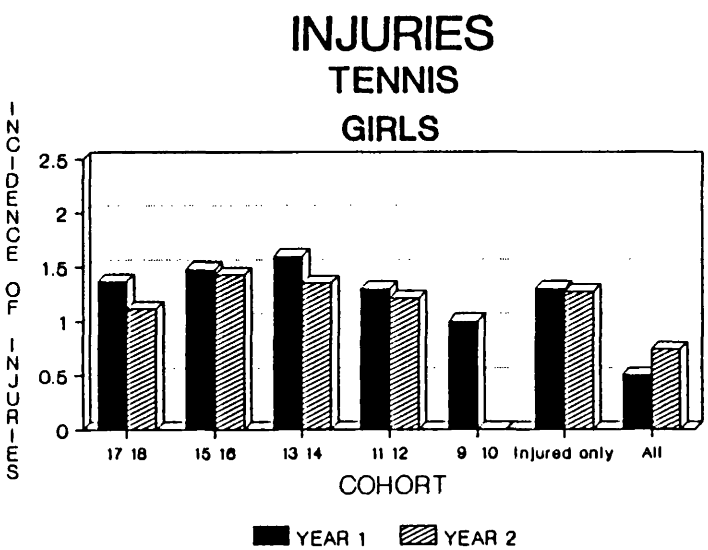




3.A.1. Incidence of injuries among young male athletes







3.A.2. Incidence of injuries among young female athletes

3.A.a.1. Acute and overuse injuries

3.A.a.1.1. **Football**

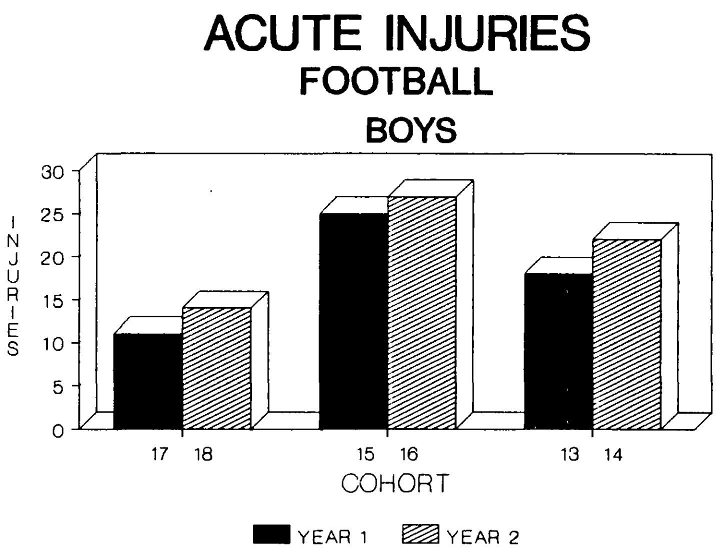
The 1973 footballers cohort (aged 15 and 16 in the two years of the study) suffered from a greater number of acute and overuse injuries than the 1971 (aged 17 and 18) and 1975 cohort (aged 13 and 14) (Figure 3.A.3.). The number of acute injuries tended to increase in all the age cohorts in the second year of the study. While suffering from at least twice as many overuse injuries as their fellow sportsmen born in 1971 and 1975, the number of overuse injuries suffered from in the two years of the study actually decreased in the 1973 boys.

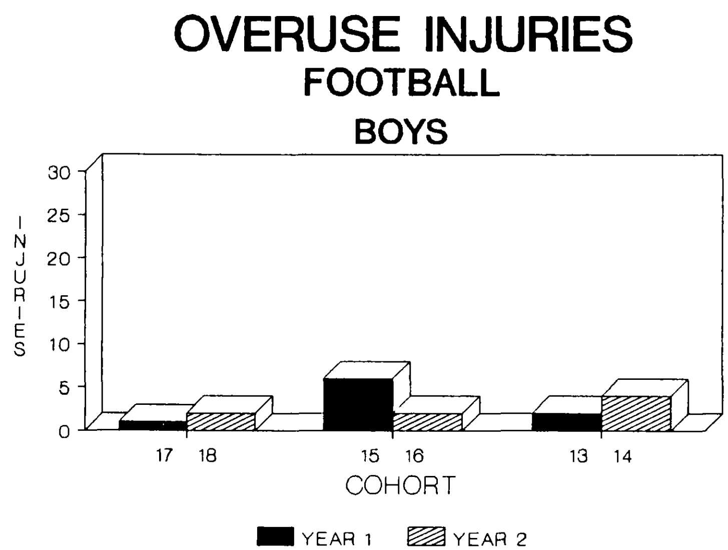
Figure 3.A.1. shows the incidence of injuries in young footballers, divided by cohort year.

Footballers showed a non significant tendency to increase the average number of injuries, except in the 1973 cohort (i.e. aged 15 and 16 over the two years). The injured boys suffered from an average 1.53 injuries in year 1, and 1.73 in year 2. For the whole population of young footballers the average number of injuries per player increased from 0.9 in year 1 to 1.22 in year 2.

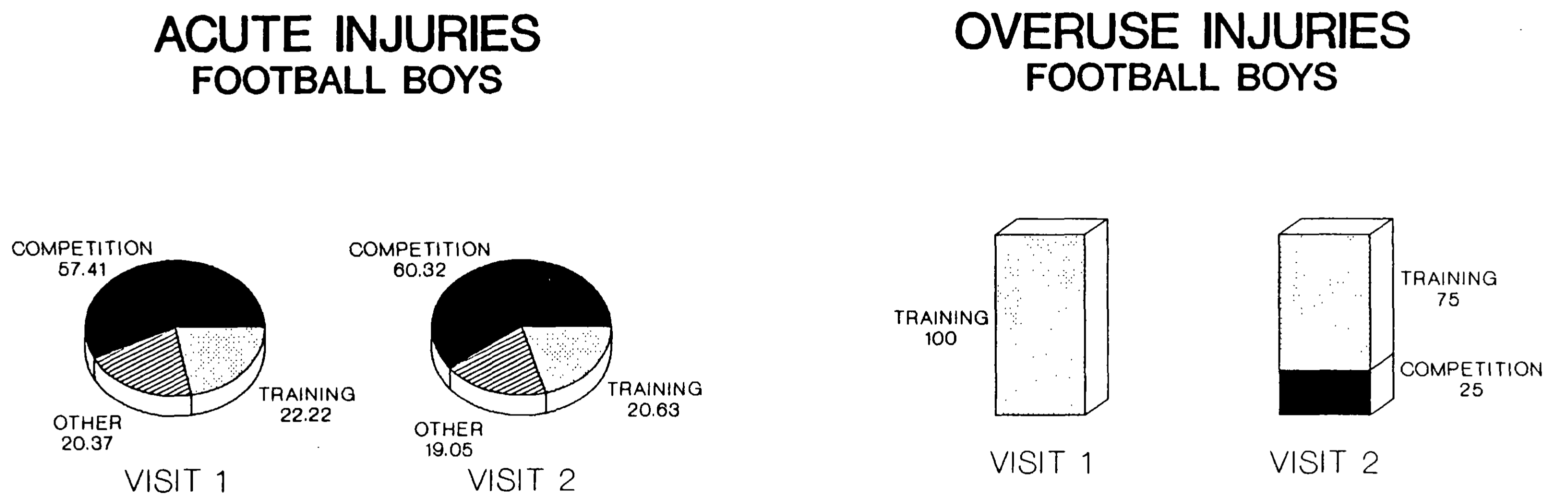
Injuries were also classified according to the events producing them, i.e., training, competition and occasions other than their main sport. Figure 3.A.4. shows the findings in this particular respect for both acute and overuse injuries in the two years of the study. It appears that young footballers suffered from acute injuries in competition-situations in about 60% of cases in year 1 and year 2, with training and occasions other than their main sport accounting for about 20% per each year.

In the first year, all overuse injuries became apparent during training. However, in the second year overuse injuries were noticed in training in only three-quarters of the subjects, the other quarter being noticed during matches.





3.A.3. Absolute number of acute and overuse injuries in football



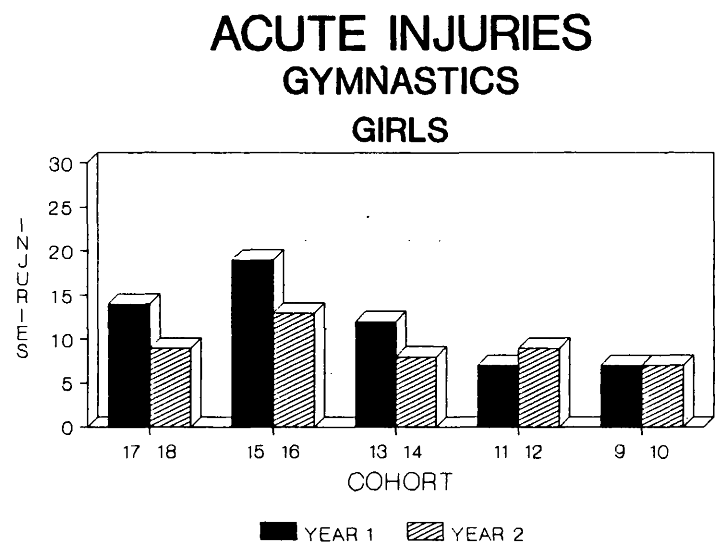
3.A.4. Context of injuries among male footballers

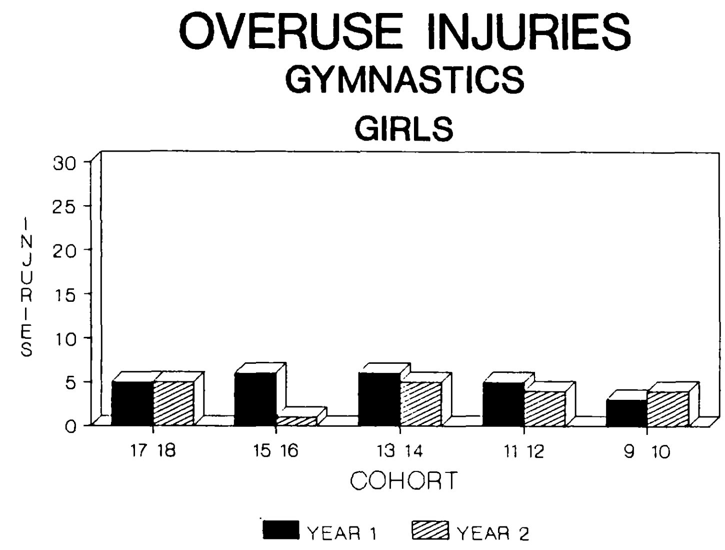
3.A.a.1.2. <u>Gymnastics</u>

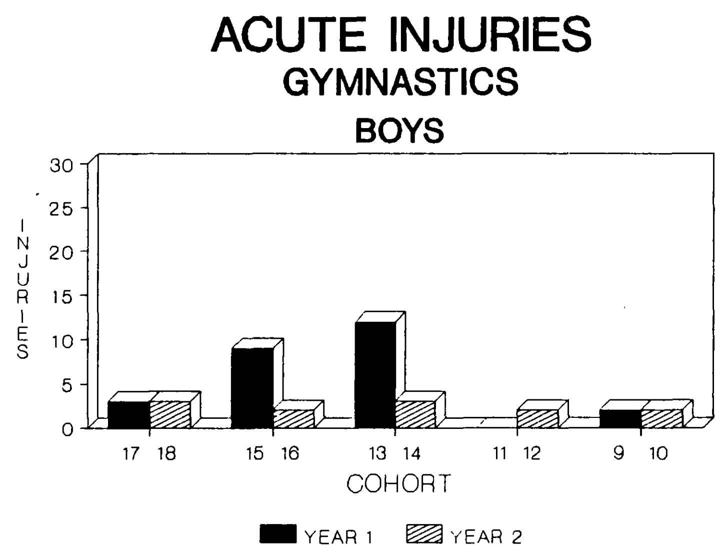
In gymnastics, the injury situation appeared to be gender specific. Young girl gymnasts in the 1973 cohort, aged 15 and 16 in the two years of the study, suffered from the greatest number of acute and overuse injuries (Figure 3.A.5.), with the youngest cohorts being the least affected by acute injuries. The situation in year 2 showed that the number of acute injuries decreased in the 1971 (aged 18 years) to 1975 (aged 14 years) cohorts, staying constant or increasing in the remaining two cohorts. The absolute number of overuse injuries remained constant in the 1971 cohort (aged 18 years), increased in the 1979 one (aged 10 years), and decreased in all the others.

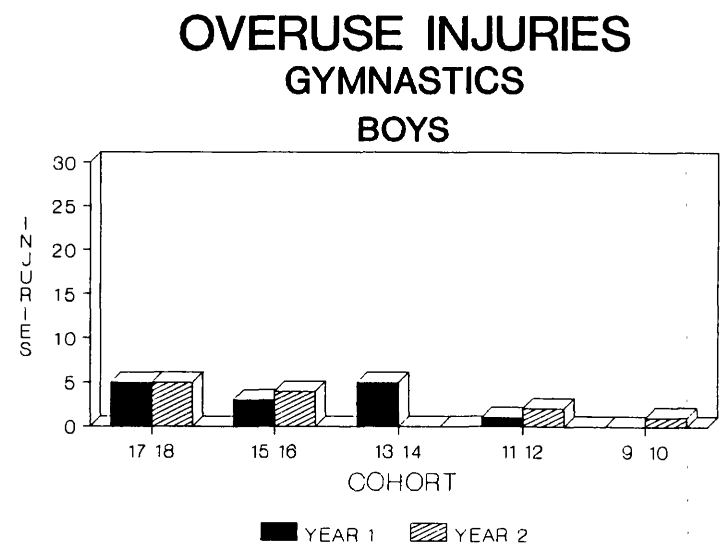
Given the decreasing cell size of the 1971 cohort (aged 18 years), injury incidence actually increased from 1.72 to 2 injuries per injured athlete from year 1 to year 2 (Figure 3.A.2.), while decreasing, albeit slightly, in all the other instances. This produced an overall decrease of the rate of injury from 1.03 to 0.91 injury per year per girl, and a decrease from 1.61 to 1.41 injuries per year for those gymnasts injured at least once.

Training accounted for the majority of acute injuries in both year 1 and year 2, decreasing from nearly 78% in the first year to 65% in the second (Figure 3.A.7.). Injuries caused by occasions other than gymnastics doubled, but injuries sustained during competition stayed fairly constant at about 11%.

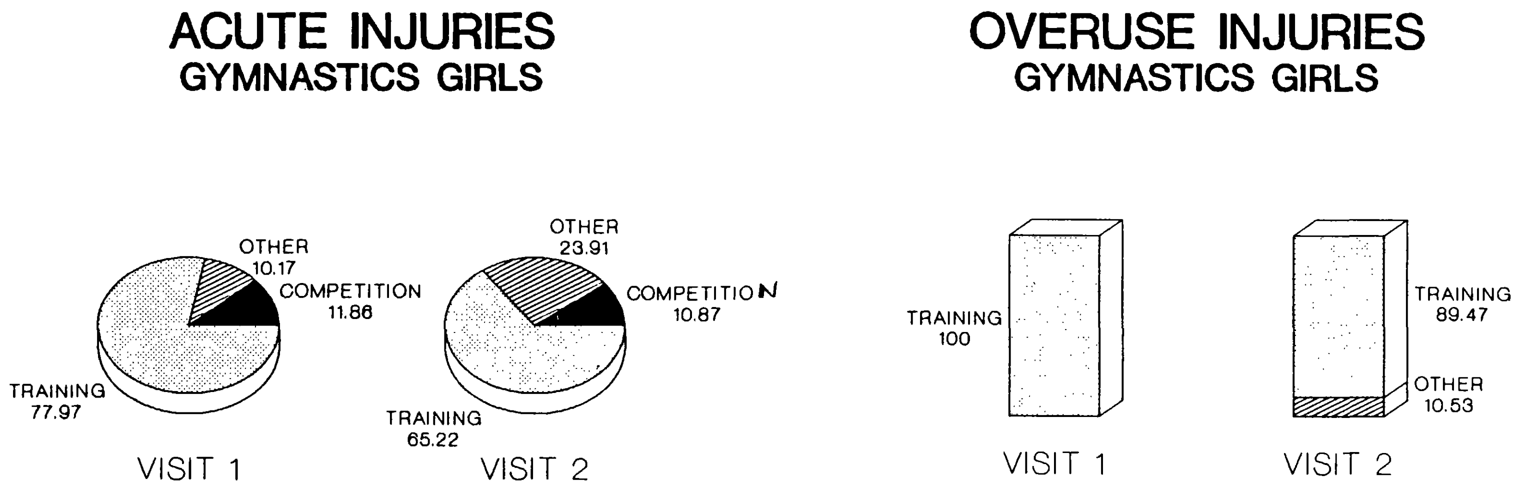




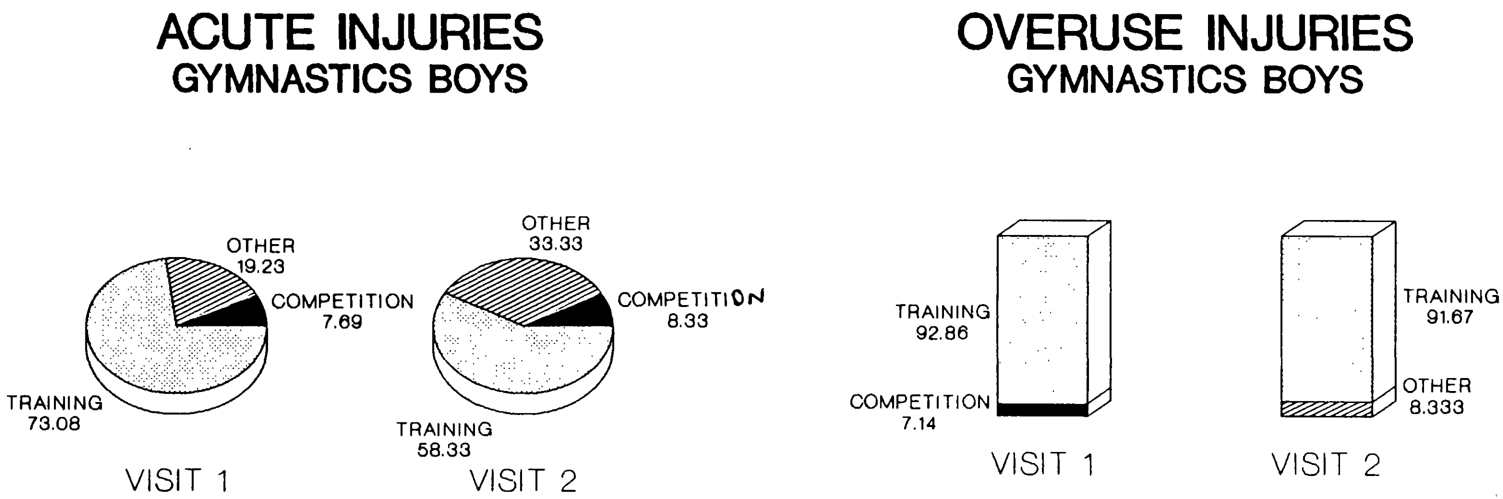




3.A.5. Absolute number of acute and overuse injuries in gymnastics



3.A.6. Context of injuries among female gymnasts



3.A.7. Context of injuries among male gymnasts

While training accounted for all the overuse injuries in year 1, occasions other than gymnastics caused about 10% of all overuse injuries in year 2.

The absolute number of acute injuries that young male gymnasts suffered from increased from 3 to 12 from the 1971 (aged 17 years) to the 1975 cohort (aged 13 years) in year 1, to decrease sharply thereafter, with the 1979 (aged 9 years) boys suffering only from two injuries (Figure 3.A.5.). The situation in year 2 was different, with all cohorts suffering from only two or three injuries each.

The 1971 (aged 17 and 18 years) and 1973 (aged 15 and 16 years) boys suffered from the greatest number of overuse injuries, while the 1979 cohort (aged 9 and 10 years) did not suffer from any. In year 2, the decrease in acute injuries corresponded to an increase in the absolute number of overuse injuries which either stayed constant or increased in all cohorts, except the 1975 cohort (aged 14 in the second year of the study), where they did not suffer from any.

The incidence of injuries was different in the various cohorts in the two years of the study (Figure 3.A.1.), ranging from at least one in the 1977 (aged 11 and 12) and 1979 (aged 9 and 10 years) cohorts, to peak to 2.1 injuries per injured child per year in year 1. The two younger cohorts still suffered from only one injury per year, the 1971 boys (aged 17 and 18 years) stayed constant at 1.6 injuries per year whilst the 1973 cohort increased from 1.33 to 2, and the 1975 cohort decreased from 2.1 to 1.5 injuries per year. In general the rate of injury decreased both for the injured children and the whole sample.

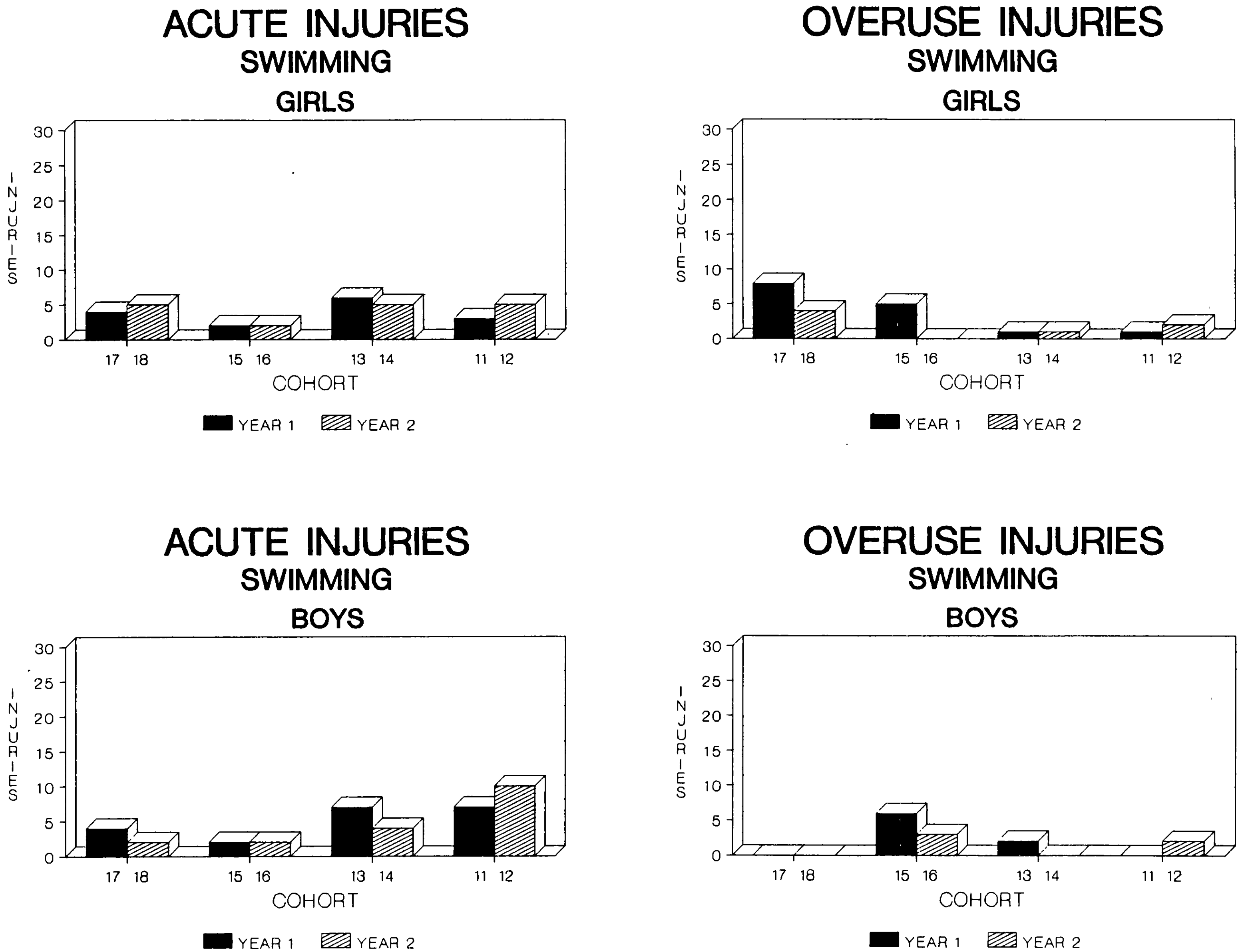
Competition accounted for only about 8% of acute injuries, while training-induced acute injuries decreased from 73% in year 1 to 58% in year 2. Occasions other than the main sport accounted for about 20% of the injuries in year 1, and above 30% in year 2. Over 90% of the overuse injuries in both years were noticed during training (Figure 3.A.7.).

Girl gymnasts showed a pattern of injuries similar to that reported by their male counterparts, both male and female gymnasts being about ten times more likely to be injured in training than in competition.

3.A.a.1.3. **Swimming**

Swimming is traditionally considered a low impact sport, given its non-weight bearing nature, and this was reflected by the rate and nature of injuries in both girls and boys.

Examining all the cohorts in both years (Figure 3.A.8.), the absolute number of acute injuries was above 5 only in the 1975 cohort in year 1, decreasing to 5 in the following year. The number of injuries increased in the two extreme cohorts, the 1971 (aged 17 and 18 years) and 1977 (aged 11 and 12 years), remaining constant at 2 in the 1973 cohort (aged 15 and 16 years in the two years of the study). Overuse

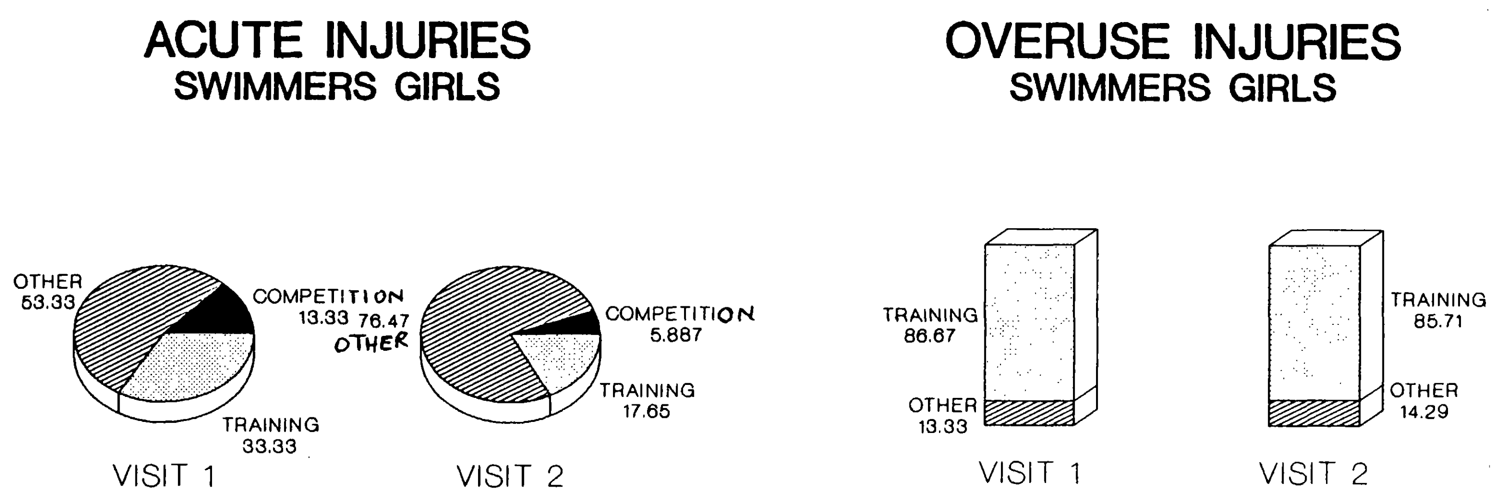


3.A.8. Absolute number of acute and overuse injuries in swimming injuries halved from 8 to 4 in the 1971 cohort (aged 17 and 18 years), disappeared completely in the 1973 girls (aged 15 and 16 years), and remained constant or increased slightly in the youngest two cohorts.

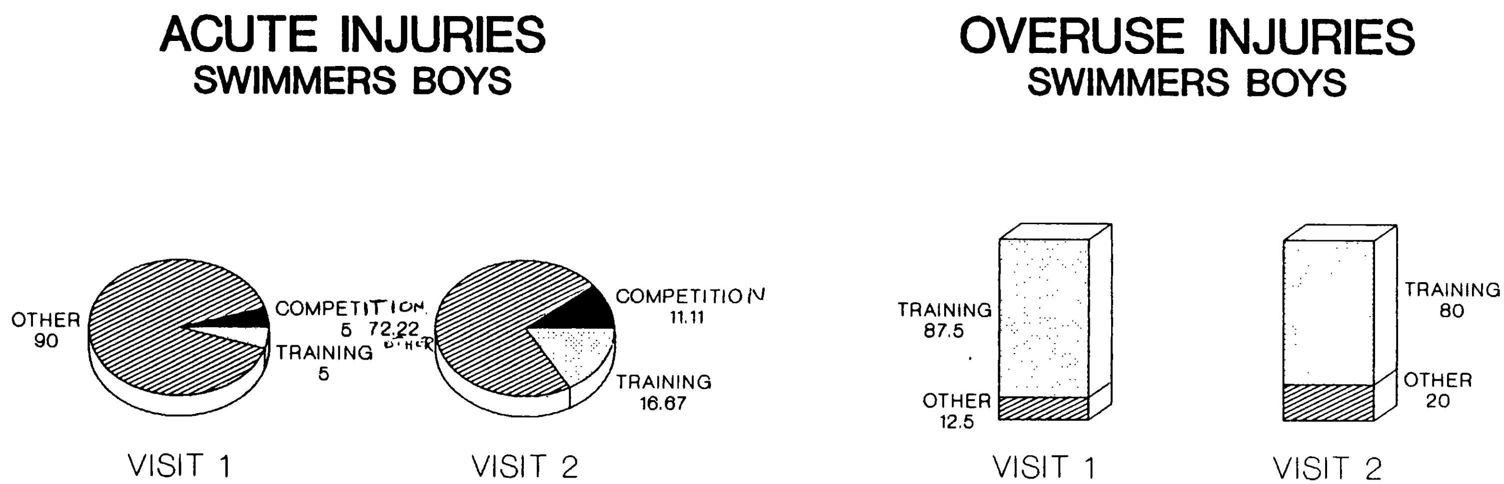
The annual injury rate showed a general decreasing trend in the 1971 cohort (aged 17 and 18 years) (Figure 3.A.2.). The injured girls suffered from 1.7 injuries per year in year 1 and 1.1 injuries per year in year 2. Only the 1977 cohort of young girl swimmers significantly increased their rate of injury from 1 to 1.4 injuries per year. The rate of injury in the whole group of young female swimmers was more than halved, falling from 0.91 to 0.43 injuries per year.

While approximately 85% of overuse injuries in both years of the study were noticed during training (Figure 3.A.9.), the remaining 15% were noticed outside their main sport. Training was responsible of approximately 30% of acute injuries in year 1 and 15% in year 2. Occasions other than the main sport caused 53% and 76% of acute injuries in the two years of the study, respectively, with competition-induced acute injuries decreasing from 13% to approximately 6%.

Boy swimmers suffered from the lowest number of both acute and overuse injuries observed for the four sports (Figure 3.A.8.). They suffered from at most 7 acute injuries in year 1 for the 1975 (aged 13 and 14 years) and 1977 cohorts (aged 11 and 12 years) and from 10 acute injuries in year 2 for the youngest children.



3.A.9. Context of injuries among female swimmers



3.A.10. Context of injuries among male swimmers

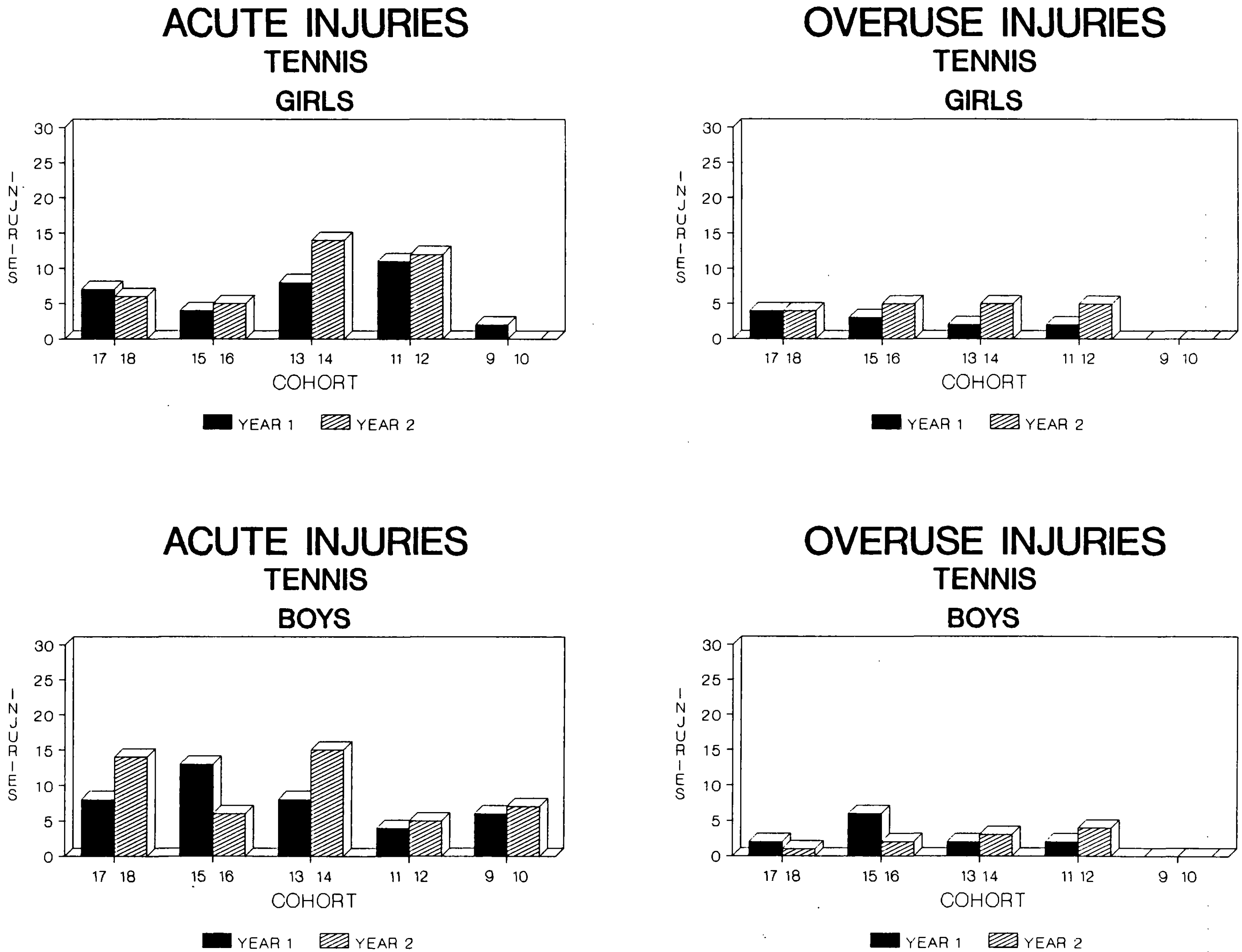
The absolute number of acute injuries tended to remain constant or to slightly decrease in all but the 1977 cohort (aged 11 and 12 years). The young male swimmers participating in the TOYA study reported a very low number of overuse injuries, the lowest recorded in the study. None were reported by the 1971 boys (aged 17 and 18 years), by the 1975 boys (aged 13 and 14 years) in year 2 and by the 1977 boys (aged 11 and 12 years) in year 2. The cohort most commonly affected by overuse injuries was the 1973 one (aged 15 and 16 years), reporting 6 and 3 overuse injuries, respectively, in year 1 and year 2.

The overall rate of injury in young male swimmers (Figure 3.A.1.) was low, with 0.5 and 0.48 injuries per each year of the study, respectively. When only the injured athletes were considered, these figures increased, and were similar to those found in the other sports, being 1.55 injuries per year in year 1 and 1.23 injuries per year in year 2. The most affected cohort was the 1971 one, with 2 injuries per year in year 1 but only 1 in year 2, with the 1975 boys following at 1.8 injury per year in year 1 and 1.3 in year 2. In general, there was a trend towards a lower rate of injury incidence in all cohorts except the 1977 cohort, similar to that found in their female counterparts. The young male swimmers increased their rate of injury from 1.4 to 2 injuries per year during the study.

Both male and female swimmers appeared to be more prone to injury outside the swimming pool, with occasions other than swimming accounting for 90% of their acute injuries in year 1 and 72% in year 2 (Figure 3.A.10). The percentage of acute injuries due to training more than trebles from year 1 to year 2, and doubles in the case of competition. No overuse injuries were sustained because of competition, with training accounting for 87.5% of them in year 1 and 80% in year 2, the remaining being caused by occasions other than their main sport.

3.A.a.1.4. <u>Tennis</u>

The absolute number of acute injuries suffered from female tennis-players is shown in Figure 3.A.11. The greatest number of acute injuries were experienced by the 1975 girls (aged 13 and 14 years) in year 2 (14 injuries) and by the 1977 girls (aged 11 and 12 years) in year 1 (11 injuries). The 1979 cohort (aged 9 and 10 years) suffered from only 2 injuries in year 1, and did not suffer from any in year 2. Nevertheless, the general trend was for a slight increase in the number of acute injuries, except for the 1971 girls (aged 17 and 18 years), who showed a decrease from 7 to 6 acute injuries. A similar situation was found in overuse injuries, with the 1979 girls (aged 9 and 10 years) showing no injuries in both years, while the other cohorts remained stable, or slightly decreased their absolute number of overuse injuries.

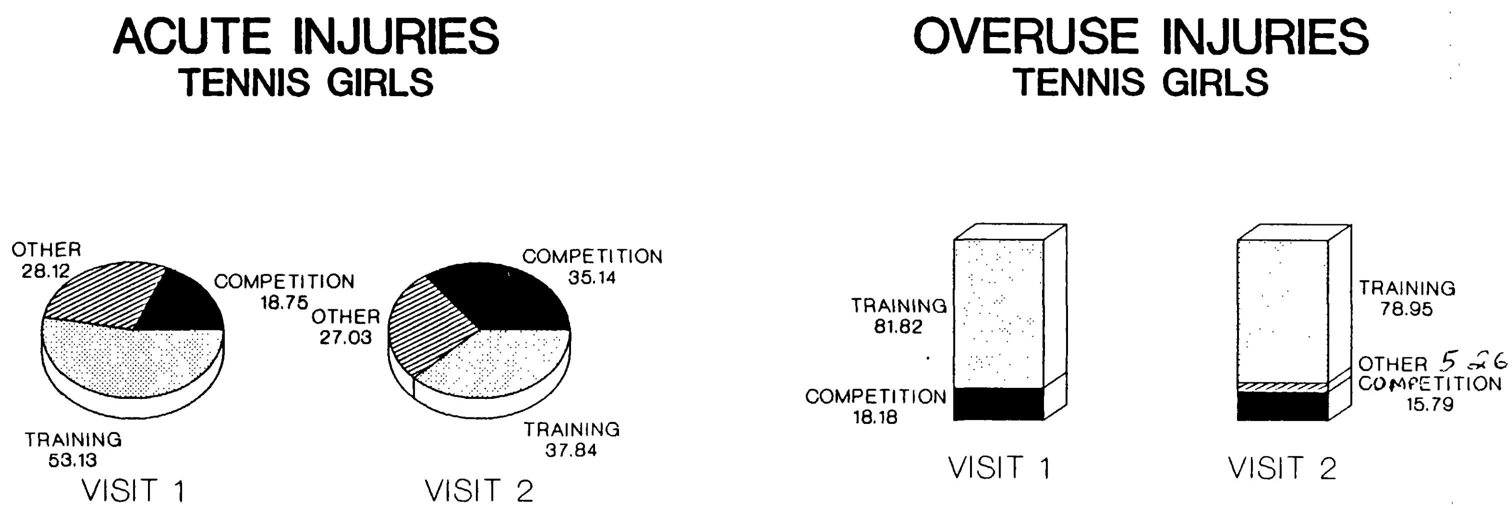


3.A.11. Absolute number of acute and overuse injuries in tennis

When the incidence of injuries was examined (Figure 3.A.2.), a decreasing trend from year 1 to year 2 was identified when the cohorts were looked at separately. The rate of injury remained constant at about 1.3 per year per injured child, but increased from 0.5 to around 0.75 when all the young girl tennis players were considered.

Training accounted for about 50% of all acute injuries in young female tennis players in year 1, matches accounted for less than 20% in year 1, and the rest were accounted for by activities other than tennis (Figure 3.A.12.). In year 2, both training and competition accounted for acute injuries (more than 35% each) with 27% being suffered from activities other than tennis. In both years, more than 80% of the overuse injuries became apparent during training. In year 1 there were no overuse injuries outside the sport, and 18% became apparent during matches. Competition accounted for around 16% and activities other than tennis for about 5% of overuse injuries in year 2.

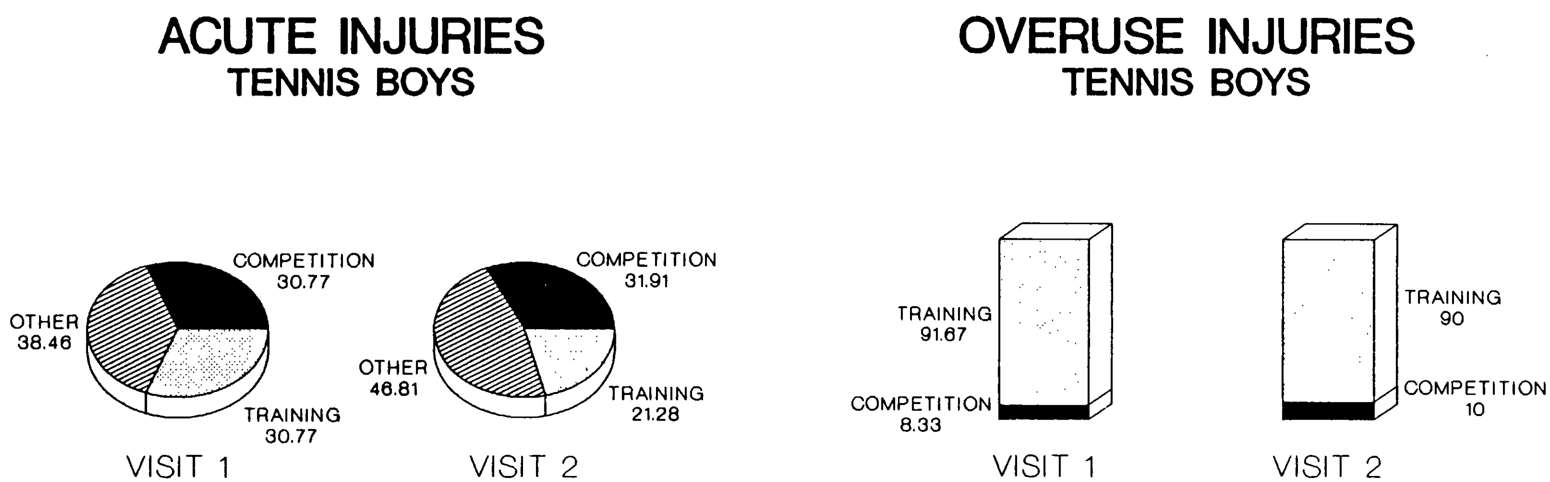
Male tennis-players showed an increase in the absolute number of acute injuries in all cohorts except the 1973 one (aged 15 and 16 years) (Figure 3.A.11.). This increase was more marked in both the 1971 and 1975 cohorts who nearly doubled their acute injuries in the second year. The absolute number of overuse injuries decreased in the two older cohorts, increased in the 1975 (aged 13 and 14 years) and 1977



3.A.12. Context of injuries among female tennis players (aged 11 and 12 years), and remained constant at 0 in the youngest.

The annual incidence of injury for the 1971 (aged 17 and 18 years), 1975 (aged 13 and 14 years) and 1979 (aged 9 and 10 years) cohorts increased, while the 1973 (aged 15 and 16) and 1977 (aged 11 and 12 years) cohorts decreased (Figure 3.A.1.). Overall the rate of injury in those injured at least once increased, as did the rate in the whole male tennis players' sample.

Acute injuries suffered in year 1 were caused in about 40% of cases by activities outside their main sport, with training and competition accounting for 30% each (Figure 3.A.13.). In year 2, while the acute injuries caused by competition remained fairly constant, there was an increase to 46% in the acute injuries due to activities outside the main sport, with training injuries decreasing to 21%. In both years, the proportion of overuse injuries which became evident during training and competition remained fairly constant at about 90% and 10%, respectively. No overuse injuries were noticed outside tennis.



3.A.13. Context of injuries among male tennis players

3.A.a.1.5. Differences between sports

From the analysis of the data reported in Figures 3.A.1 to 3.A.13., several differences between sports in the type and incidence of injuries emerge. In boys, the incidence remained constant for swimming, showed a reduction in gymnastics, and an increase in football and tennis. The situation in female gymnasts and tennis-players was similar to that reported in their male counterparts, while injury incidence rate dropped significantly in swimmers. This phenomenon could be due to the fact that those children who were injured dropped out of the study.

The difference between the four sports in the frequency of injuries sustained during competition, training or outside their sport is shown in Figures 3.A.4., 3.A.6., 3.A.7., 3.A.9., 3.A.10., 3.A.12. and 3.A.13. These differences were only just statistically significant. Among the boys, footballers (Figure 3.A.4.) were more likely to be acutely injured during a match than in a training session, with a ratio of over 2 : 1. In gymnastics (Figures 3.A.6. and 3.A.7.), the opposite was true. In swimmers, the data suggested that they were more likely to become injured during activities not directly related to their main sport. No such trend was evident in tennis players (Figure 3.A.13.) who, although more frequently injured in training, were almost as likely to be injured in competition or outside their sport. Swimmers showed a reverse trend (Figures 3.A.9. and 3.A.10.), and male and female swimmers were more prone to injury outside a swimming session. If the injury was directly connected with their sport, it is more likely to have happened during a training session. Finally, female tennis-players showed a more precise pattern (Figure 3.A.13.), with more injuries occurring during training than at any other time.

The different distribution of the causes of injuries in the four sports was probably due to the intrinsic nature of the sport and to the age of the participants. For example, in football it is customary for young players to engage in two matches per week, probably with one training session interspersed between them. This could account for the large proportion of acute injuries experienced during a competition. The situation is reversed in gymnasts, in whom the majority of acute injuries are caused by training. The fact that swimming is a low-impact/low-injury risk sport can be seen both from the low absolute number of acute injuries suffered by young swimmers, and from the overwhelming majority of these that are sustained outside their sport.

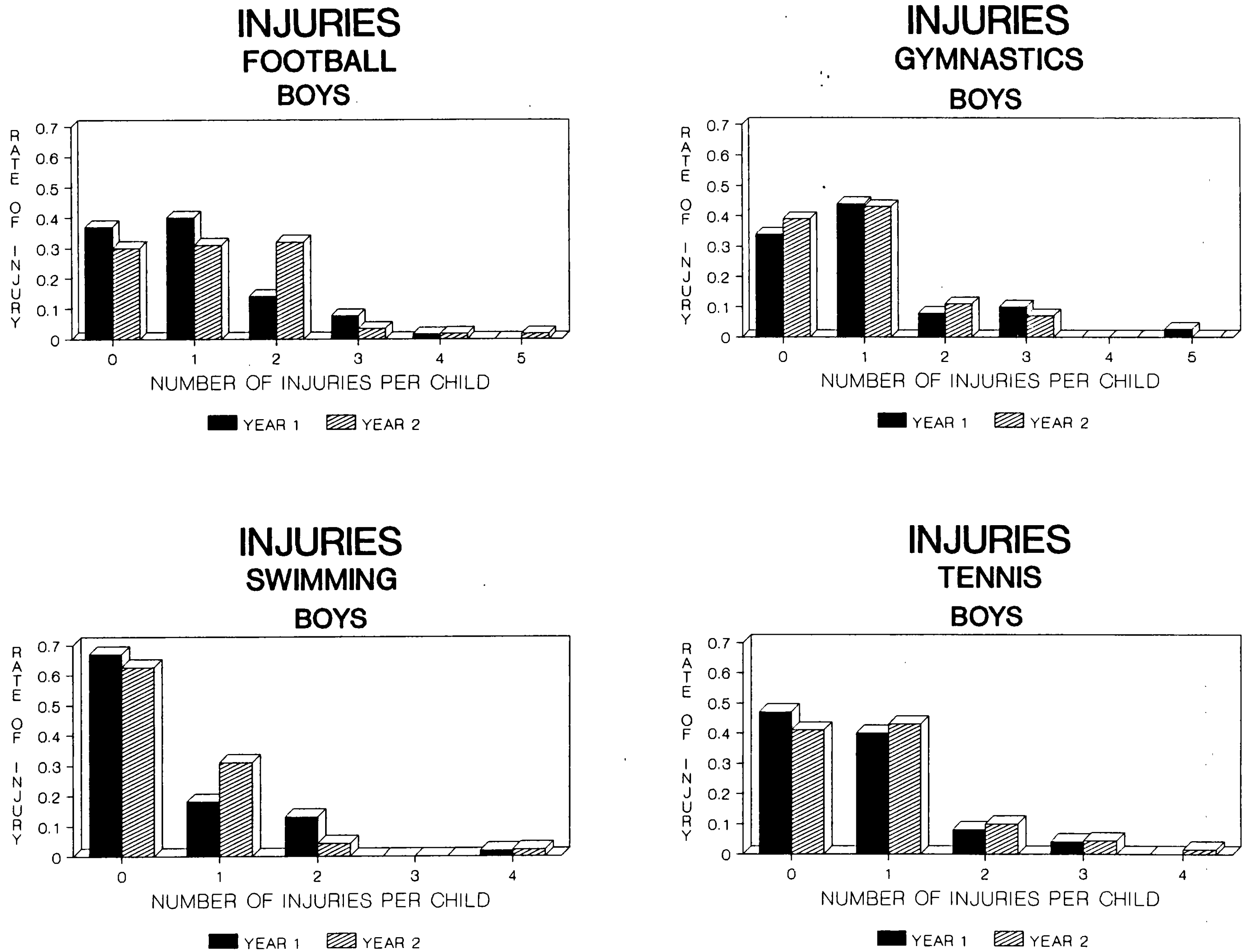
Overuse injuries can be considered the most typical of all sports injuries, as 75% to 100% of them became apparent during training sessions. The pattern of overuse sports injuries shown by the different sports probably reflected the different requirements of the sports. For example, in gymnastics high level competition is started at an early age, and continued throughout adolescence.

3.A.a.1.6. One or more injuries

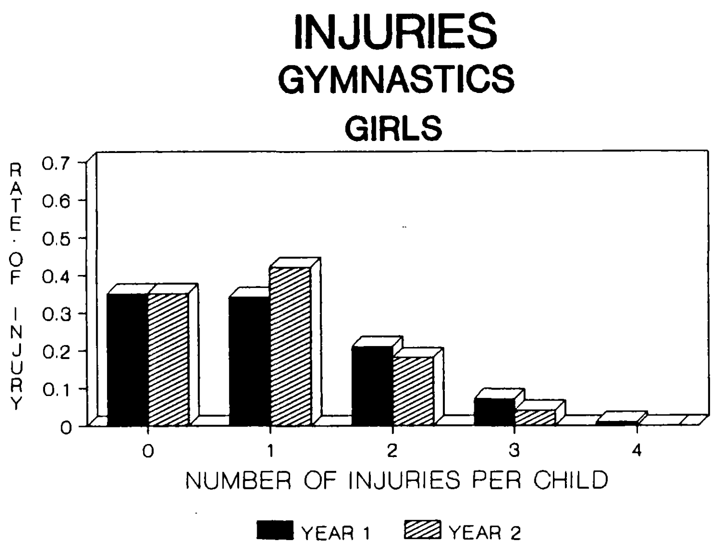
A further measure of how each sporting activity is injurious is given by the proportion of the children who were injured at least once during the study. This is shown in Figures 3.A.14. and 3.A.15. Very few children suffered from more than 2 injuries, and the relative proportion in this respect varies according to the different sports.

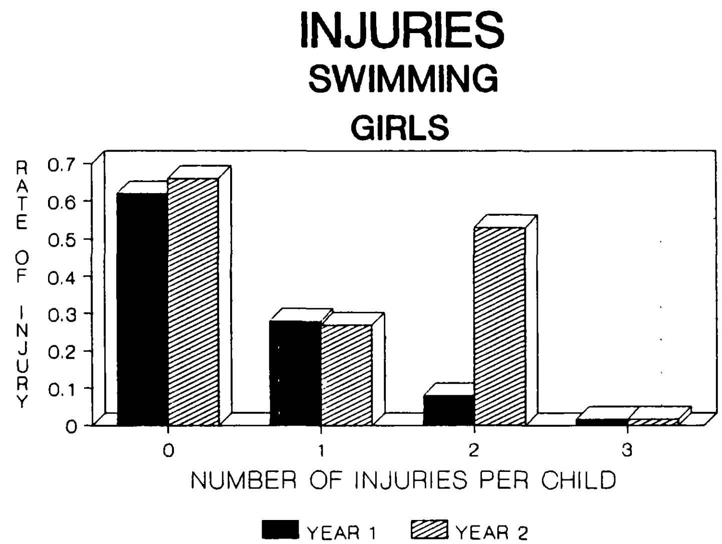
In football (Figure 3.A.14), only 25% of the sample of the first year and 40% of the second year sample suffered from more than two injuries per year. In gymnastics (Figure 3.A.14.), the proportion of boys suffering from one injury remained fairly constant at about 42%, while the boys who did not experience any injuries actually increased in year 2. The proportion of children with the highest number of injuries decreased as well. On the other hand, the proportion of girl gymnasts with no injuries in the two years of the study remained constant at about one-third of the population (Figure 3.A.15.), the girls with one injury only increasing from 34% to 42%, while those with two injuries or more decreased slightly.

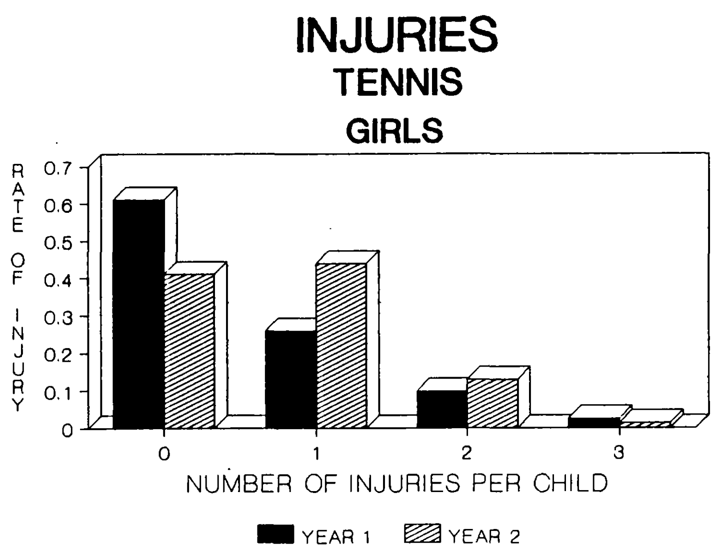
Swimming is a low-risk sport. This is reflected by the proportion of both male and female young swimmers not injured at all during the two years of the study. In both years more than 60% of the young athletes did not suffer from any injuries. Among the boys (Figure 3.A.14.), 18% of them at year 1 and 31% at year 2 suffered from one injury, while the proportion of swimmers suffering from more than two injuries per year declined. The proportion of girls with one injury rose from 26% to 44%, and the proportion of girls with more than two injuries per year remained constant (Figure 3.A.14.).



3.A.14. Rate of injury among young male athletes







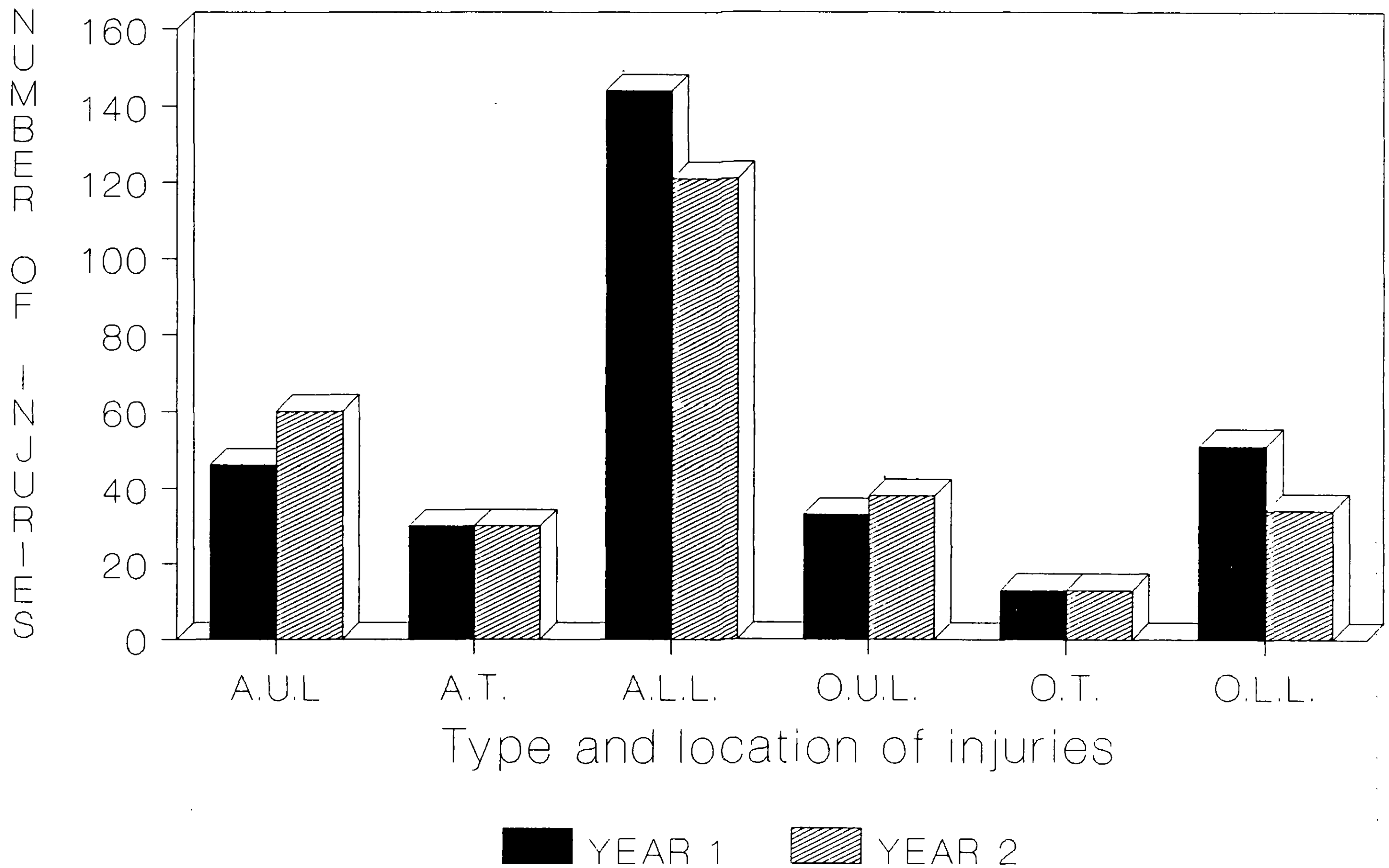
3.A.15. Rate of injury among young female athletes

Tennis is a non-contact sport, and more than 40% of the boys playing it for the two years of the study were not affected by any injuries, although an almost equal proportion did suffer from one injury (Figure 3.A.14.). The remaining 15% suffered from more than two injuries in both years. Girl tennis-players were not injured at all in 60% of cases in year 1, but this proportion decreased to 41% the year after. This corresponded to a sharp increase in the number of girls with one injury, and a smaller increase in those with two. The number of girls with more than three injuries, already small to start with, further decreased in year 2 (Figure 3.A.15.).

3.A.a.1.7. <u>Location of injuries</u>

Both the acute and overuse injuries were grouped according to their location in trunk, upper limb and lower limb, and the incidence per injured child was calculated. Details are given in Figure 3.A.16, where A.U.L. = acute injuries of the upper limb; A.T. = acute injuries of the trunk; A.L.L. = acute injuries of the lower limb; O.U.L. = overuse injuries of the upper limb; O.T. = overuse injuries of the trunk; O.L.L. = overuse injuries of the lower limb. The number of acute injuries by location decreased slightly in the two years of the study, remained constant in the overuse injuries of the trunk, increased in the overuse injuries of the upper limb, and decreased in the overuse injuries of the lower limb. However, these differences were not significant.

INJURIES



3.A.16. Injuries by location: absolute number and incidence

3.A.a.2. TRAINING AND INJURIES

It has been suggested that the quality and the amount of training may influence the rate of occurrence of sports injuries (Micheli, 1983). The TOYA study has collected data about the time that each child spends training per week, and is in the process of collecting from the coaches data on training style.

To test the above hypothesis, the ANOVA technique was applied to analyse the data about acute and overuse injuries, grouped together and divided into trunk, upper and lower limb injuries for both years. The only mildly significant differences were found for the overuse injuries of the trunk in year 1, and for the upper limb overuse injuries in year 1. The differences were not at a high significance level, so no definite comments may be made.

The rate of injury per 1000 hours of exposure to the sport practised was calculated (Table 3.A.1. and Figures 3.A.17. and 3.A.18.).

TABLE 3.A.1.

Injuries per 1000 hours of exposure to the sport practised

FOOTBALL

Cohort	YEAR 1	YEAR 2
1971	23.5	26.2
1973	111	68.4
1975	113	96.7

GYMNASTICS

	BOYS		GIRLS	
Cohort	YEAR 1	YEAR 2	YEAR 1	YEAR 2
1971	9.6	11	29.8	22.1
1973	17.3	9.4	32.2	21.5
1975	24.8	3.5	28.2	21.5
1977	1.6	5	20.3	21.9
1979	5.6	8.4	18.5	20.2

SWIMMING

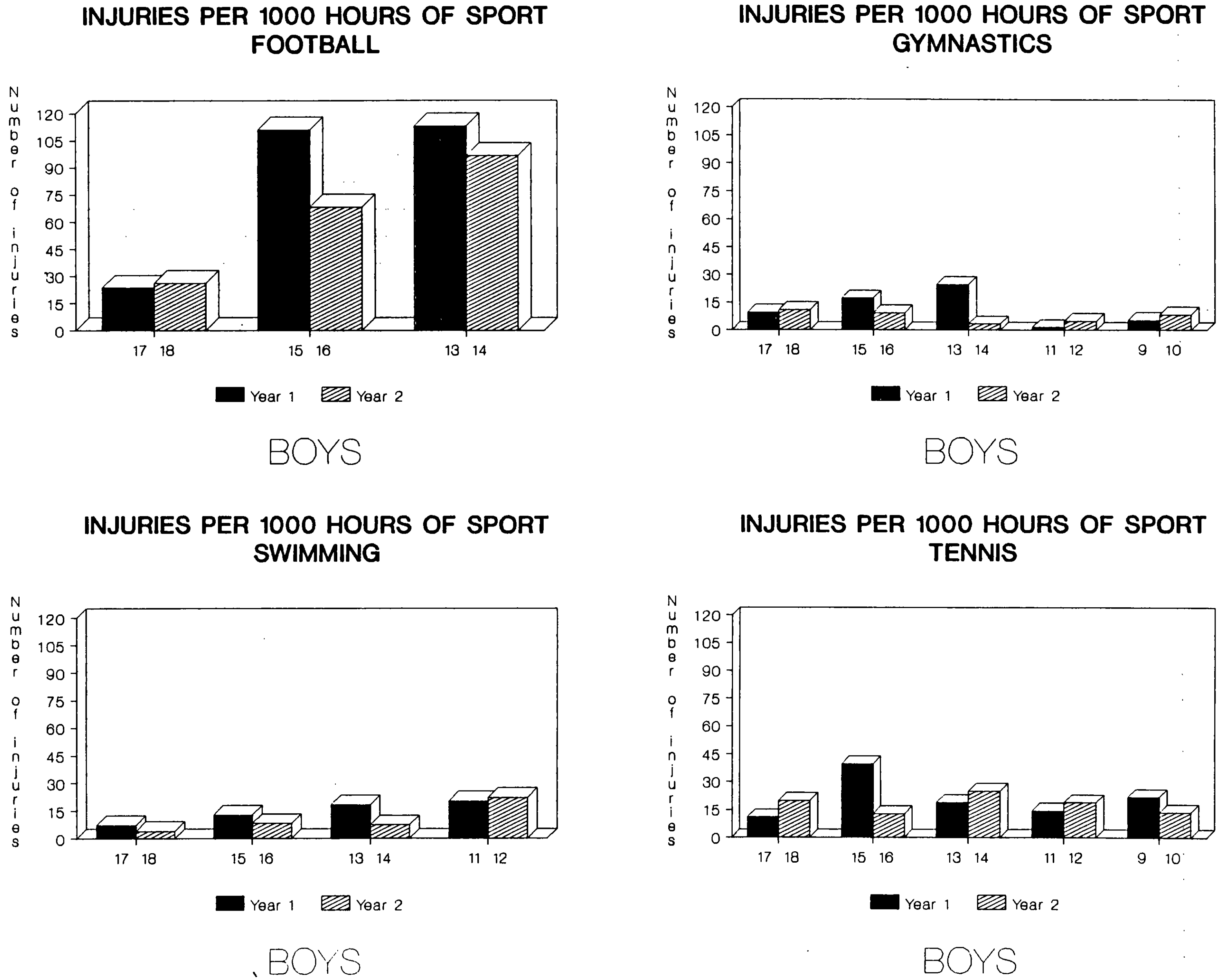
	BOYS		GIRLS	
Cohort	YEAR 1	YEAR 2	YEAR 1	YEAR 2
1971	7.2	4	16.4	14
1973	12.8	8.2	11	3.1
1975	18.3	7.4	16.1	11.8
1977	20.3	22.2	11.4	13

TABLE 3.A.1. (continued)

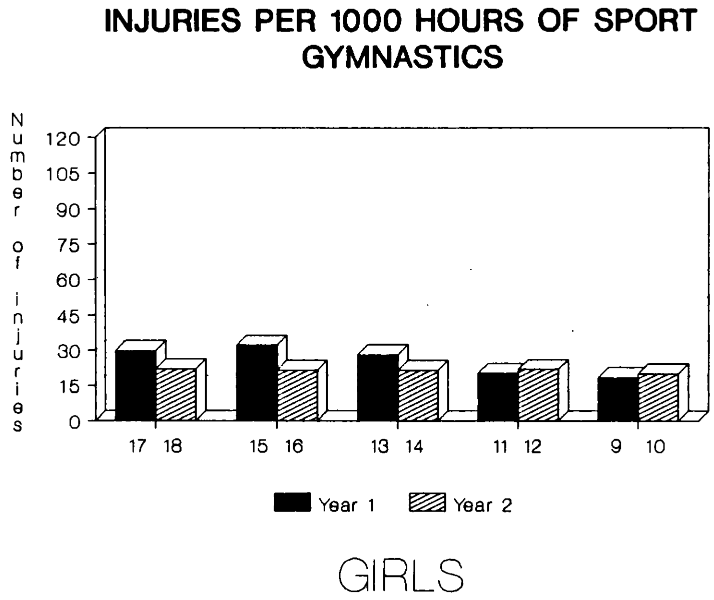
Injuries per 1000 hours of exposure to the sport practised

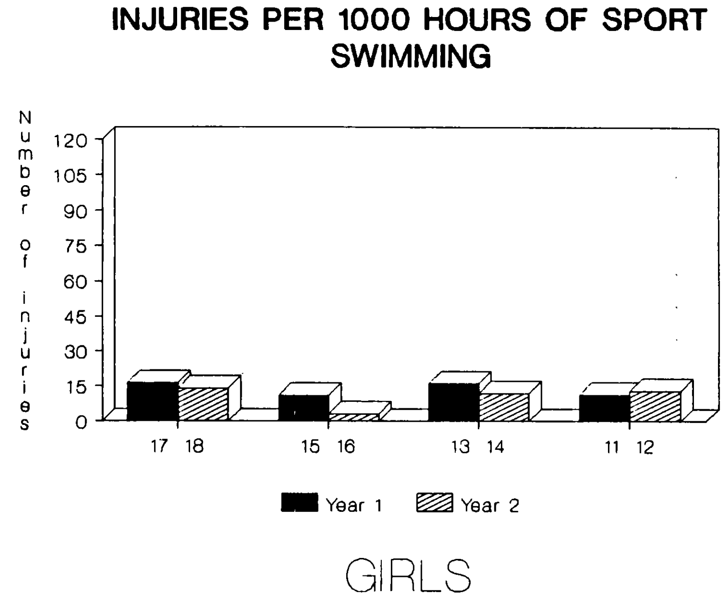
TENNIS

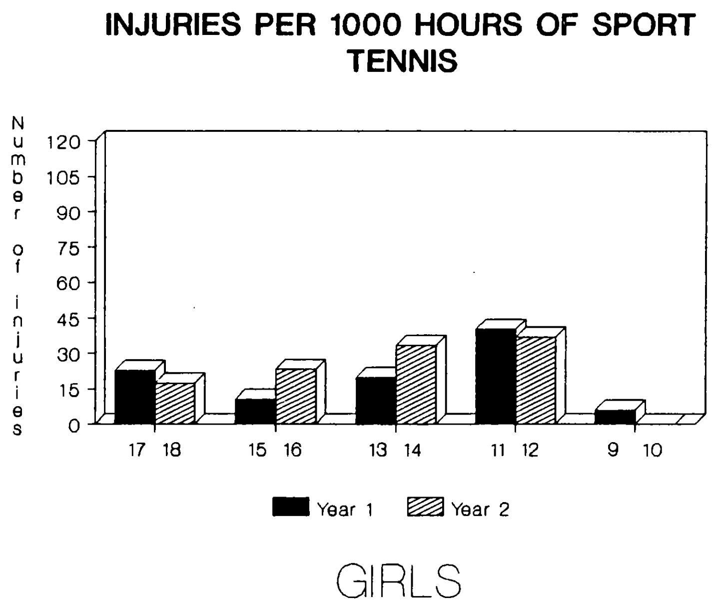
	BOYS		GIRLS	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Cohort				
1971	11.1	19.8	22.9	17.5
1973	39.7	12.9	10.7	23.3
1975	18.9	25	19.9	33.4
1977	14.5	18.9	40.3	37.0
1979	21.9	13.7	6.1	0



3.A.17. Injuries per 1000 hours of exposure to sport: boys







3.A.18. Injuries per 1000 hours of exposure to sport: girls

The younger cohorts of footballers suffered from a significantly greater number of injuries per 1000 hours of exposure to sports activities than the older ones ($p < 0.001$) and all the other sports in both genders ($p < 0.00001$). Among the gymnasts, girls suffered from a significantly greater number of injuries than their male counterparts ($p < 0.01$), while younger boy swimmers were injured less often than girl swimmers ($p < 0.03$). In tennis, no statistically significant differences between the sexes were evident. Older footballers suffered from a comparable number of injuries than the children practising the other sports. On the other hand, younger footballers suffer from up to 3 times the number of injuries of the more frequently injuried athletes practising other sports (tennis players).

3.A.a.3. <u>PHYSIOLOGICAL CHARACTERISTICS AND INJURIES</u>

The hypothesis that young athletes with none, one or more than two injuries could be in some ways different from each other was tested using ANOVA analysis. The dependent variables were the various flexibility and isometric strength values, and height and weight. The injuries were considered 'in toto' as the sum of all the acute and of all the overuse injuries, and covariated for the amount of time spent training each week, the sport, the children's age and their gender. When the sums of all the acute and of all the overuse injuries were tested separately and combined, only modest but non significant differences were found in year 2 for the total number of injuries for the frontal splits and the left quadriceps strength. The children who suffered from none, one or more than two acute injuries were modestly different from each other for their frontal splits ($F = 1.38$, $p = 0.03$).

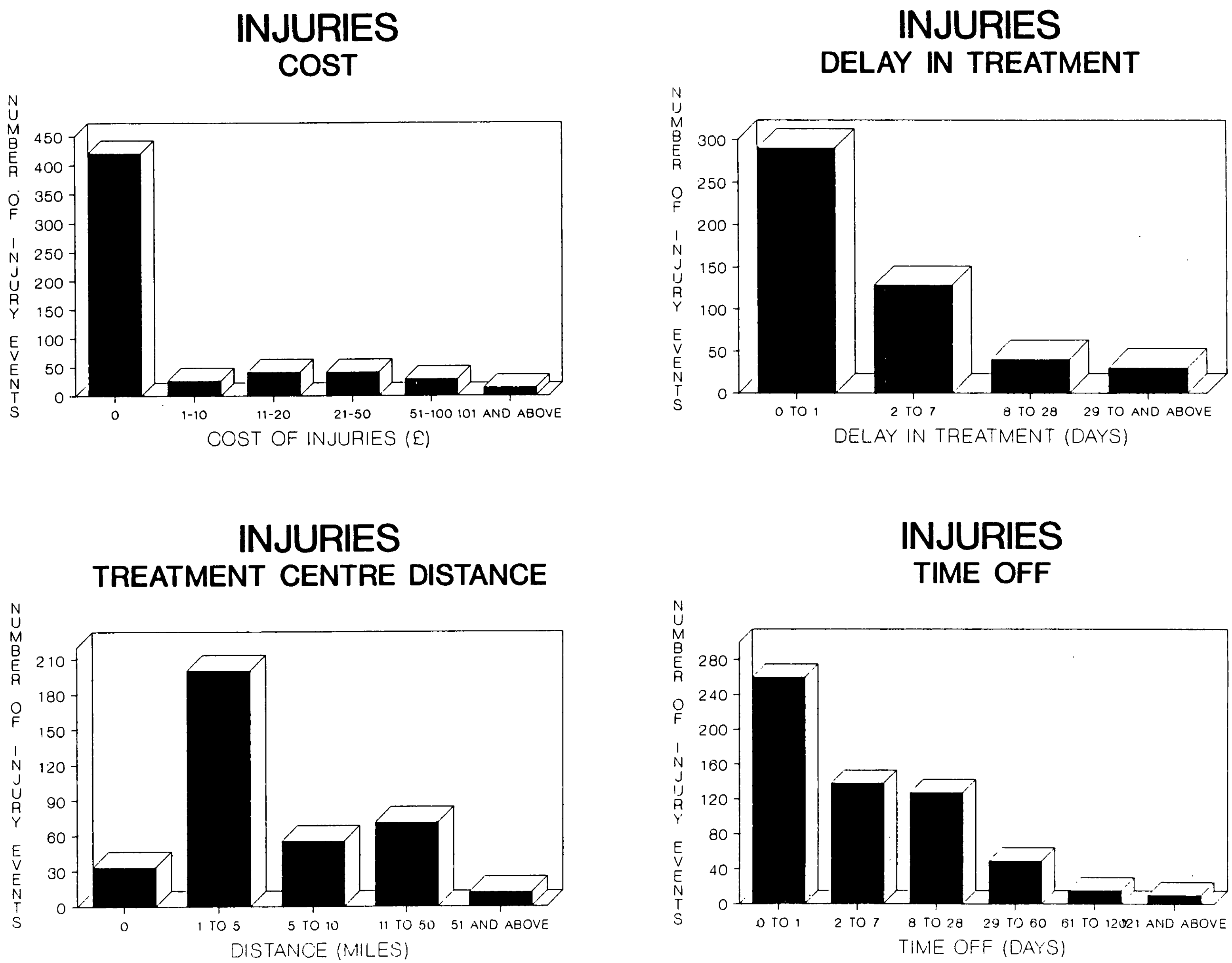
A similar strategy was employed to see whether the children suffering from none, one or more than two injuries to their trunk, upper limb or lower limb were different from each other. The differences found were not statistically significant.

3.A.a.4. **THE IMPACT OF INJURIES**

There are several possible ways of assessing the impact of a sporting injury. In the TOYA Study, we chose to examine the cost of a sports injury, and the time off sport. Also, the delay between injury and treatment and the distance between where the injury took place and the treatment site were assessed. These variables are shown in Figure 3.A.19., which summarises the data for both years in the four sports.

Most injuries resulted in only one day or less of time off sport. These injuries were capable of disrupting a training session but did not significantly alter the training process of these youngsters.

In 138 cases, two days to one week had to be spent recovering from the injury. In a similar number of injurious events, i.e. 129, eight days to four weeks were required. A total of 94 injuries required



3.A.19. The impact of injuries

more than one month of interruption to training and, in one case, eight months were necessary for complete recovery to take place.

Although not specifically studied, it was evident from talking to the children, that they rarely undertook alternative forms of training to maintain their fitness level. In this respect, gymnasts were different from the other children, as they continued to go to the club to train the body part which had not been injured. It is probably advisable to practise some form of alternative sporting movements when injured. Although the specificity of each form of training is well recognised, some workers have shown that maximal treadmill oxygen uptake can be maintained in moderately trained middle-distance women runners after one month of endurance cycling (Moroz & Houston, 1987), and programmes of water-running after sports injuries are being implemented in North America (Bishop et al., 1989).

3.A.a.5. <u>THE TREATMENT OF INJURIES</u>

3.A.a.5.1. Actual treatment

Most of the injured children obtained prompt treatment, and 291 injuries were treated within 24 hours (Figure 3.A.19.). In 128 cases up to one week was necessary to obtain treatment, and in a further 80 cases a week elapsed before consulting somebody. The reasons for such a length of time were not investigated, but they may have been either intrinsic to the injury (i.e. the injury did not particularly interfere with the training process), or psychological.

When a sports injury was treated, it tended to be treated locally (Figure 3.A.19.). In 33 cases, the injuries were treated on site. This occurred mainly in footballers, as most clubs have a physiotherapist or individuals with first aid or paramedical training attached to them. This pattern was also found in all sports when the injury occurred during a competition, when either medical or paramedical personnel were available on site. In 200 cases, the treatment centre was within five miles of the home of the injured child, and in a further 55 cases it was within 10 miles. In most of these cases, the children and their parent should have been able to cover the distance by public transport. In 72 injuries, up to 50 miles had to be travelled, and in 13 cases more than 51 miles were necessary to reach the treatment centre (This category included a young girl tennis player who was injured abroad, and travelled 200 miles to be treated). Financial assistance was given in 31 out of 153 cases where payments had been made. This occurred mainly in the most expensive cases, and about 40% of the families who had paid £100 or more were refunded. In the £200+ region, expenses were refunded in full. Financial assistance was given by the club in four cases, by an insurance company in 23 cases, and by a sponsor in one. It was not specified in the remaining three cases.

Injuries were treated without apparent cost to the family in 73% of cases (Figure 3.A.19.). In the remainder, the cost of treatment of up to £10 was paid in 26 cases. In 41 cases this increased up to £20, and in an equal number of cases up to £50 was paid. Only a small minority of injuries required greater payment than this but in one case, where all treatment was administered privately abroad, the injury cost £1000. It would appear that the vast majority of the sports injuries were treated without additional cost to the family. This may reflect both the availability of the NHS service, and the fact that clubs have either paramedical facilities on site or have local arrangements with doctors or physiotherapists. Also, the young athletes in a national squad were generally treated on site. Most of the injuries suffered were trivial enough not to require more than one day off training, no complicated treatment being required.

Data on the treatment referral pathway were available in 489 injuries (Figure 3.A.20.). After an injury had occurred, it was treated in the first instance by a doctor in 222 cases, or by a physiotherapist in 203 cases. In the remaining 65 cases, either no consultation was made, or a coach took care of the injury; this occurred nearly four times more often than an osteopath being consulted. Despite the prompt intervention outlined above, an injury required further treatment in 307 instances. When this occurred, a physiotherapist was consulted on nearly

50% of occasions, followed by the Accident and Emergency Departments (12%) and by General Practitioners (11%). Children were referred to a hospital out-patient department in 14 cases. This was equal to only half of the times an osteopath was consulted.

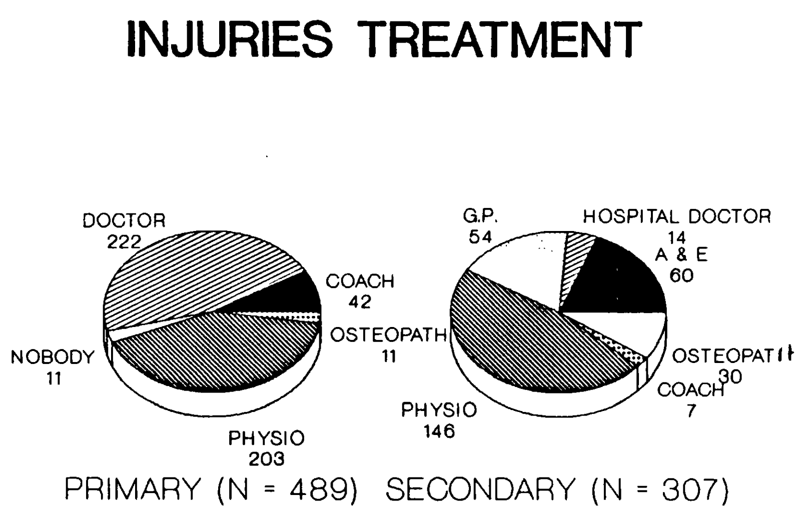
If a second consultation was not sufficient (this happened in 268 cases), a physiotherapist was involved in 180 cases. Hospital out-patient departments assumed a more important role, as they were consulted in 51 cases. Accident and Emergency Departments still saw 26 sports injuries, with GP and osteopaths seeing three and 8 cases, respectively. Finally, 65 injuries needed even further attention. This was given in nearly equal cases by physiotherapists and hospital out-patient departments, while a General Practitioner with a particular interest in sports injuries was consulted in six cases. Accident and Emergency Departments played a minor role, seeing only two cases, while osteopaths still saw about 10% of injuries at this stage.

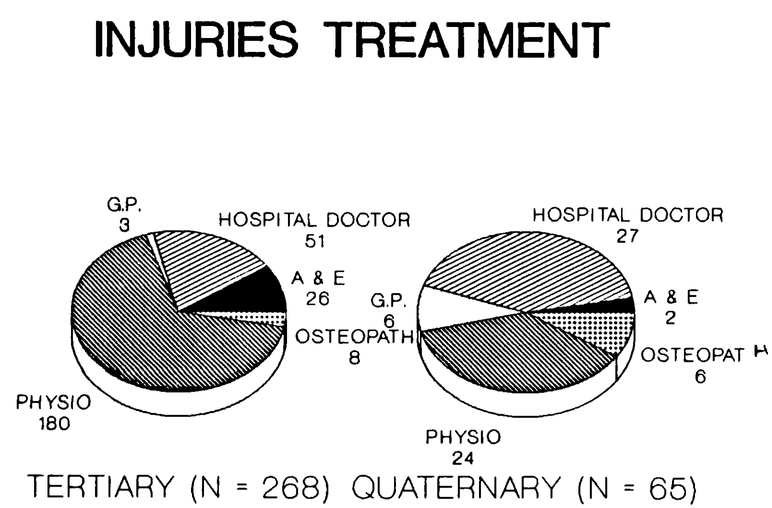
The most common form of treatment was rest, which was carried out in 55.8% of the injuries, followed by cryotherapy, which was practised in 32.8% of injuries. Immobilisation played some part in 25.4% of injuries, while physiotherapeutic practices, such as gentle mobilisation, massage, heat, ultrasound and laser-therapy were used, alone or in various combinations, in about three-quarters of cases. Only in six cases was some form of surgery required, generally for minor lacerations. One knee arthroscopy was carried out in a footballer for a rupture of the anterior cruciate ligament, and only about 15% of injuries required some form of medication, with 59 injuries being treated with non-steroid anti-inflammatory drugs, and two with steroid injections.

Although some form of treatment was required in the vast majority of injuries, this was only rarely of an invasive nature, and required drug intervention only in a minority of cases.

The findings of the TOYA Study in the field of injuries show a very low rate of injuries in these intensively-trained young athletes, especially when the data presented are compared with the North American data (Table 1.C.1.).

Also, when injuries did occur, these were not likely to be serious enough to warrant surgery. These discrepancies with the reported literature may be due to several factors. For example, a bias in the selection of the sample. In order to take part in the TOYA study, the children had to be intensively trained, or to be successful at their sport, or the coaches and governing bodies had to foresee potential sporting success. In several cases, the criterion of intensive training was not met (see Section 2.A.6., pp. 62-68), but, despite this, most of the children were successful athletes. It is known that athletic ability is to a large extent genetically determined and it is





3.A.20. Actual treatment of injuries

possible that these children were genetically endowed with a more resistant musculo-skeletal system (Astrand & Rodhal, 1986). Also, psychological testing revealed that the young athletes in the cohort showed an extremely high spatial awareness, and this could have some influence on the incidence of injuries (data collected by other members of the TOYA team, and not shown in this thesis). Finally, if a child were injured too often, the chances of having been nominated for this study were small.

A further possible cause for the low incidence of injuries is the definition of "injury" which, when compared to other studies, was both stringent and specific. In practice, if an injury had no effect on the training process, or if advice had not been sought, it was not identified in this study.

Another cause for the low incidence of injuries could be the retrospective nature of the study. Some studies have been conducted attaching a doctor or another health professional to a team or a club and, in this case, even minor ailments are reported and collated as injuries. Also, in a typical club or team situation only a minority of the athletes will be 'elite' and genetically gifted. In the average club athlete, then, a higher incidence of injuries may be expected.

Finally, the psychological habitus of the elite young athletes should be considered. If an athlete is extremely motivated, as was the case in these children, the threshold at which to consider an accident as an injury may be greater. No specific studies were performed to confirm this hypothesis.

3.A.a.5.2. **Intentional treatment**

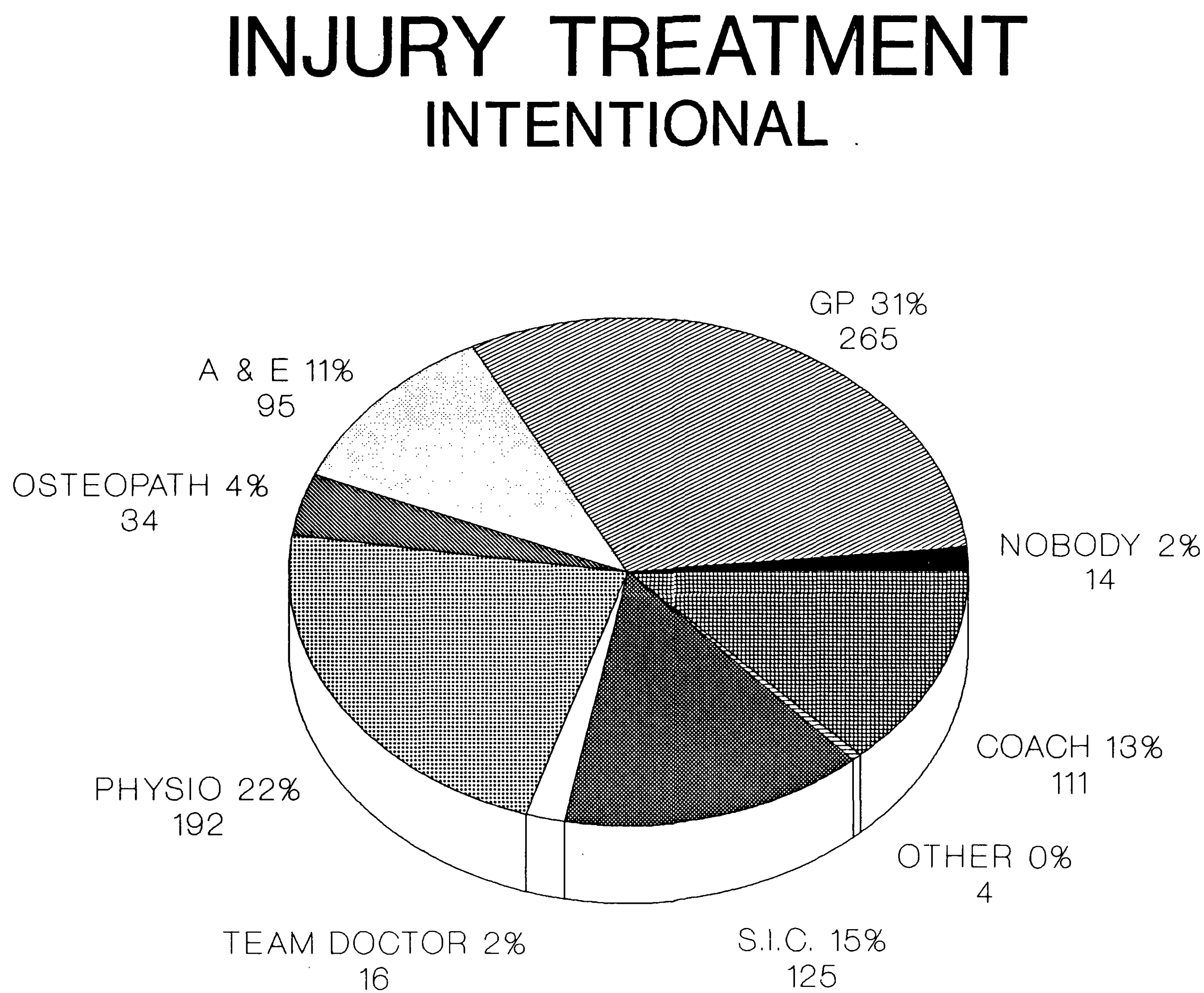
The children and parents were asked the following question: "If you had a sports related injury for which you had to take time off training, where would you go?"

Seven possible answers were given, namely:

Nobody	Hospital
Coach	Sports Injury Clinic
GP	Osteopath
Other (specify)	

The results of this survey are shown in Figure 3.A.21. In 31% of cases the family doctor would have been contacted first, followed by a physiotherapist. Sports injury clinics come third with 125 preferences (15%) while coaches would be the preferred source of primary treatment in 13% of cases. Just above 10% of the children said they would go to an Accident and Emergency Department, with the remaining 6% preferring to see some other professional. Only in 14 cases did these children say they would not consult anybody if they suffered from an injury.

As can be seen from the above, the preferred situation is quite different from the actual one. For example, while the percentage of children who actually saw a doctor in the first instance was quite similar to the one reported as preferred, this is not the case for physiotherapy, which accounted for 41% of the actual treatment and only 31% of the preferred. The preferred figure came closer to real life if it is considered that treatment in Sports Injury Clinics is generally administered by physiotherapists. In both the preferred and 'real life' survey it was evident that coaches were regarded as a possible source of treatment and, indeed, they often gave such treatment.



3.A.21. Intentional treatment of injuries

3.A.b. INJURIES: DISCUSSION

The TOYA study was not a study of the incidence of injuries. The incidence of children's sports trauma is nearly impossible to determine as it is extremely difficult to define the 'at risk' population. For example, soccer is extremely popular in Western countries. It is well recognised that a calculation of the time spent on playing football or the population at risk would only give vague figures (Tursz et al., 1986). Recent studies have shown that sports injuries may account for between 11% (Tursz et al., 1986) and 27% (Sahlin, 1990) of all childhood accidents. Comparison of results with these or other studies is difficult given the different definition of "injury", the level at which the sport is played, the exact definition of the sample studied and the type of study (retrospective or pro-spective) (Yde & Nielsen, 1990).

Sports accidents sustained by younger children are as severe and follow the same injury pattern as those experienced by older children. The reasons for this are not clear, as it is well known that younger children have less body control than older ones (MacDonald, 1985). This study has shown that the incidence of injury suffered by boys and girls is very similar, except in female gymnasts in whom it is greater. This could be due to both the specific requirements of girl gymnasts, and to the fact that girls may obtain less technical advice and less qualified coaching than their male counterparts

(Zariczny j et al., 1980).

A major difference between this study and most of the others performed in this field is that the children who took part in the TOYA study were, or were thought to have the potential to become, the elite in their particular sport. This implies that even the youngest age groups had already undergone a rigorous selection process, and had already been training for some years. The intrinsic qualities of these children have not been clarified, but, from a purely theoretical view-point, it is conceivable that in order to continue the hard training routines they undergo, they must be especially gifted. Their musculo-skeletal system, for example, could be particularly resistant to external trauma. Also, their body awareness may be genetically better developed than in 'normal' children, thus decreasing the risks of some injuries due to, for example, overbalancing.

An unusual category of accidents are those occurring to swimmers. As is shown in section 3.A., pp. 105-132 swimmers suffered from a low incidence of sports injuries. It was noticeable that several of the acute injuries suffered by swimmers were not due to swimming in itself but to slipping on wet surfaces in the swimming pool area (Sahlin, 1990). A different type of floor might reduce these accidents.

An interesting issue is the number of injuries that athletic children suffer from when corrected for the amount of time spent training and competing in their sport. When applying this approach, it is evident that contact sports are by far the most injurious ones, and football may provoke in the younger athletes up to three times the injuries that occur in the second most injurious sport, tennis. The reasons for this are speculative.

For example, the structure of football is different from that of the other sports, in that only a few hours per week are spent in training, with at least one match played each week. In this respect, tennis is probably similar to football. The difference is also likely to be due to the nature of the sport, as football is a much more physical game, requiring repeated contacts with the opponents, and hence the risk of injuries is heightened. The issue that insufficient training may be a co-factor in sports injuries (Micheli, 1983) is suggested by the finding that the quantity of football and tennis training is fairly low (see Section 2.A.6., pp. 62-68), and some of the top ranked athletes in the younger cohorts in these two sports were spending only two to three hours per week training. The number of injuries decreased dramatically in older footballers, who had either undergone a further selection, acquired greater skill, or were dedicating more time to training.

On the other hand, the two sports in which children spend a significant greater amount of time training, gymnastics and swimming, were characterised by a low incidence of injuries when corrected for the amount of time spent in the sport.

No normative data exist for the various sports. A recent prospective study of 496 young Danish footballers aged 12 to 18 years, which used a definition of injury similar to the one used in the present study, showed an incidence of only 3.7 injuries per 1000 hours of soccer played (Schmidt-Olsen et al., 1991). The incidence increased with age, and, in the older children, approximated the incidence rate of senior players (Schmidt-Olsen et al., 1991). A direct comparison with our data is not, however, feasible, given the different structure of the sport in Denmark, and the criteria used in the selection of the sample. It is however noticeable that young Danish soccer players suffer from up to approximately 30 times less injuries than their English counterparts.

Among the TOYA athletes, no fatal injuries were reported, and a very small minority required hospitalisation and/or an operation. The TOYA study only collected data for two years, so it was not possible to ascertain if any of the injuries reported resulted in long term disability, especially in the case of fractures of long bones (MacDonald, 1985).

The use of protective clothing may reduce the severity and number of sports injuries (Sandelin, 1986). For example, the use of shin guards was not widespread in youth soccer until 1990 and, by making this compulsory, a number of soft tissue and bone injuries could be avoided.

The majority of injuries did not need any time off sport and, if treatment were needed, this was given within one day in more than 60% of cases. An injury treatment centre was available within five miles of home in approximately 70% of the cases. Treatment was administered without any payment 2.5 times more frequently than when payment was made, and the highest payment made was of the order of £1000.

In about one quarter of the reported injuries, up to one week was necessary to obtain treatment. The reasons for such a length of time were not investigated but they could have been either intrinsic to the injury (i.e. the injury did not particularly interfer with the training process), or psychological. For example, young footballers may have been afraid of losing their place in the team. Equally, gymnasts may have been afraid of losing their body habitus, as periods of inactivity may result in unwanted weight gains. Furthermore, training constitutes a large part of the extramural life of these intensively-trained young athletes, and constitutes a significant part of their social life. An injury, then, may imply the sudden loss of a social structure with a special meaning for the athlete, and within which the sporting child has a status.

Doctors and physiotherapists were the professionals dealing with more than 80% of injuries in the first instance. Treatment was given by the coaches in about 8% of cases. When further treatment was needed, it was given by physiotherapists in about 50% of cases, and by a physician in a further 40%; of these, GP's were consulted in about 20% of injuries. In complicated cases, doctors tended to be consulted more often than physiotherapists. Given the structure of the referral pathway outlined, it is evident that education programmes in evaluation, prevention and primary care of sports injuries should be addressed at physiotherapists and physicians. As the coaches are the educators actually present at the time and site of a sports injury in the greatest majority of cases, they should be the target of at least some specific sports injuries courses.

Although not specifically studied, it was evident from talking to the children that only rarely did they undertake alternative forms of training in order to maintain their general fitness level. In this respect, gymnasts were different from the other children, as they continued to go to the club to train the body part which had not been injured. It is probably advisable to practice some form of alternative sporting movements when injured. Although the specificity of each form of training is well recognised, some workers have shown that maximal treadmill oxygen uptake can be maintained in moderately trained middle-distance women runners after one month of endurance cycling (Moroz & Houston, 1987), and programmes of water-running after sports injuries are being implemented in North America (Bishop et al., 1989).

In several cases, the criterion of intensive training was not met (see Section 2.A.6., pp. 62-68), but, despite this, most children in the sample were successful athletes. It is known that athletic ability is to a large extent genetically determined and it is possible that these children were genetically endowed with a more resistant musculoskeletal system (Astrand & Rodhal, 1986).

In conclusion, elite young athletes undergoing intensive training do not appear to be at increased risk of injuries when compared to an unselected young athletic population. The rate of injuries and their severity, as measured by the amount of time off training taken, appears to be low. The cost of treating a sports injury appears to be contained, and treatment is readily available at a short distance from the home of these elite young children. The long- term effects of injuries could not be evaluated given the structure of the study but no harmful middle-term effects appear to be present in the sample studied.

How these results, obtained in elite, selected young athletes, may be applied to the population of children performing intensive training without being 'elite' is not known at present.

SUMMARY

1. The children involved in the TOYA Study suffered from a low incidence of injuries.
2. There were differences in injury rate among the four sports, with swimming being the least injurious.
3. When corrected for the number of hours trained, the differences in injury rate among sports and genders were more evident, with football being responsible for three times more injuries than tennis.
4. Most injuries were treated by physiotherapists within 24 hours from occurrence.
5. The great majority of injuries were treated without direct payment from the family.
6. Strength and flexibility did not seem to exert a significant role in determining injuries in this group of elite young athletes.

3.B. FLEXIBILITY: RESULTS AND DISCUSSION

3.B.a. FLEXIBILITY: RESULTS

The results of the flexibility tests will be discussed in the order given in the **SUBJECTS AND METHODS** section. For simplicity, the results of the primary analysis of the left and right sagittal splits are omitted, as they convey the same information given by the front splits. The data for the whole population of children will be presented, and the data on each sport will be presented subsequently.

3.B.a.1. Flexibility of the upper limb and gleno-humeral joint

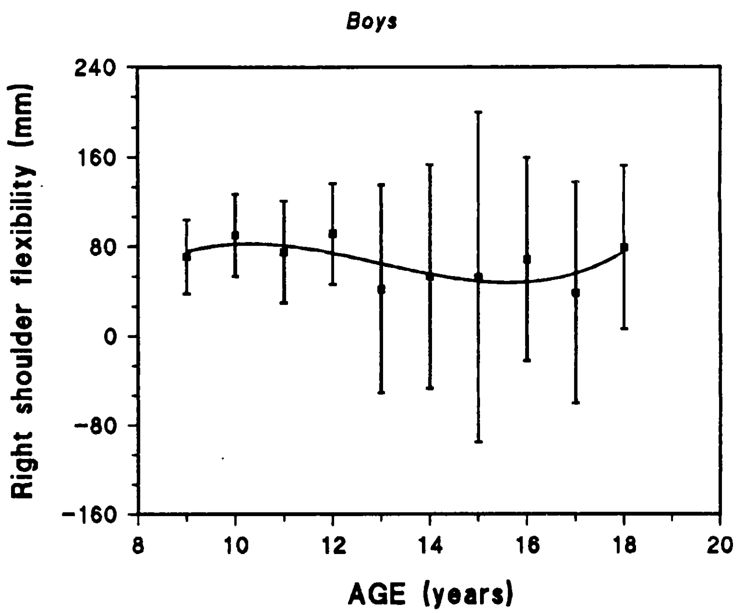
Summary data of the flexibility of the upper limb and gleno-humeral joint for both sides and for all the children are presented in Figures 3.B.1. and 3.B.2.

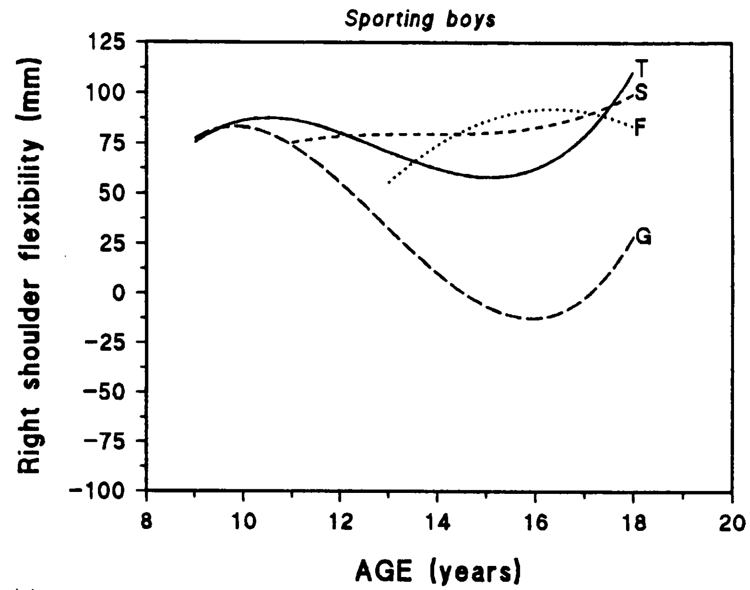
The flexibility of the gleno-humeral joint was measured using the 'cross behind the back' test, the side being determined by the elevated arm. Girls and boys were equally flexible , and this finding did not change over the two years of the study or with age. In view of the method used to measure gleno-humeral joint flexibility, cubit length was a major factor in determining the value measured.

When the results were covariated for cubit length, the age groups from 14 years onward were significantly less flexible than the younger ones ($p < 0.01$). No consistently significant effect was exerted by pubertal stage, while age was a significant covariate for girls up to 12 years. Training time did not exert any significant effect for any sport.

When each sport was considered separately, the results appeared to be sports-specific. In absolute values, girls (Figure 3.B.3. and 3.B.5.) were not significantly more flexible than boys (Figure 3.B.4. and 3.B.6.). Although highly correlated (see paragraph 3.B.a.4.), there were significant differences between right and left side of the body in all sports in both sexes, with the right side being more flexible than the left (ANOVA, $p = 0.005$). In both sexes, gymnasts were the least flexible athletes by the end of the study, with swimmers being the most flexible. Among the boys, there were no significant differences in the flexibility of the right shoulder in footballers, swimmers and tennis players on the right side, while female tennis players and gymnasts were significantly less flexible than swimmers from age 17.

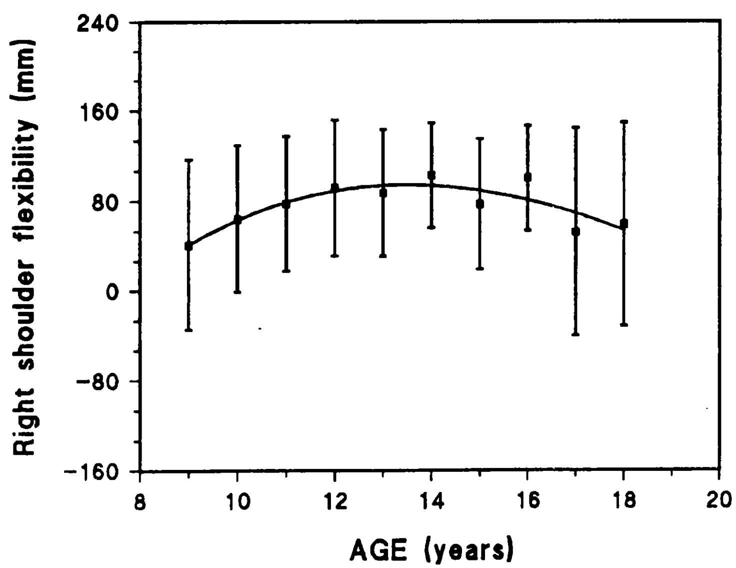
Male and female gymnasts started by being at least as flexible as the other athletes, and they increased the flexiblity of their gleno-humeral joint in a similar fashion as the other sports for at least two years. However, from 13 years, the gymnast boys became remarkably less flexible (ANOVA, $p < 0.03$), being unable to touch their middle fingers during the test (Figure). A similar behaviour was shown by female gymnasts on the left side two years later than in boys (Figures 3.B.4. and 3.B.6.). On the left side, shoulder flexiblity remained negative in girls and boys. On the right side, the male gymnasts were the only group that showed negative values. This occurred after a progressive loss of flexibility after age 11, and the tendency reverted at 17 years of age. Even when covariated for cubit length, which was significantly shorter in gymnasts of both sexes, the male gymnasts remained the least flexible athletes on both sides (ANCOVA, $p = 0.02$).



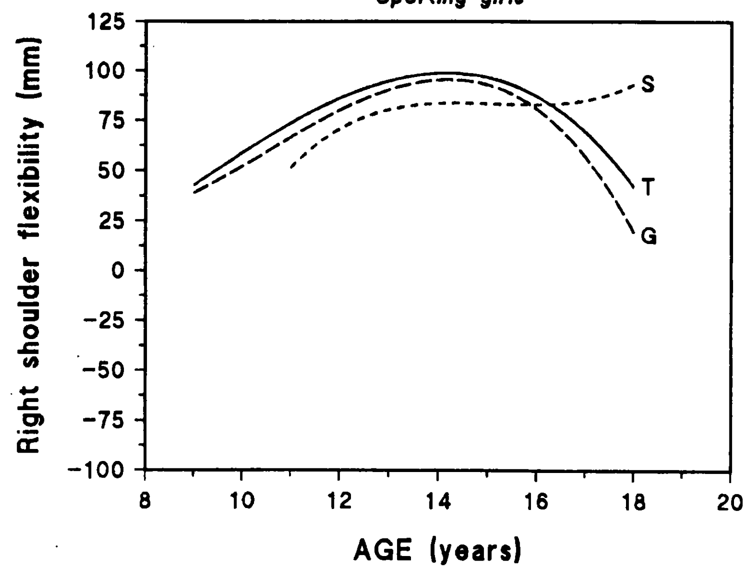


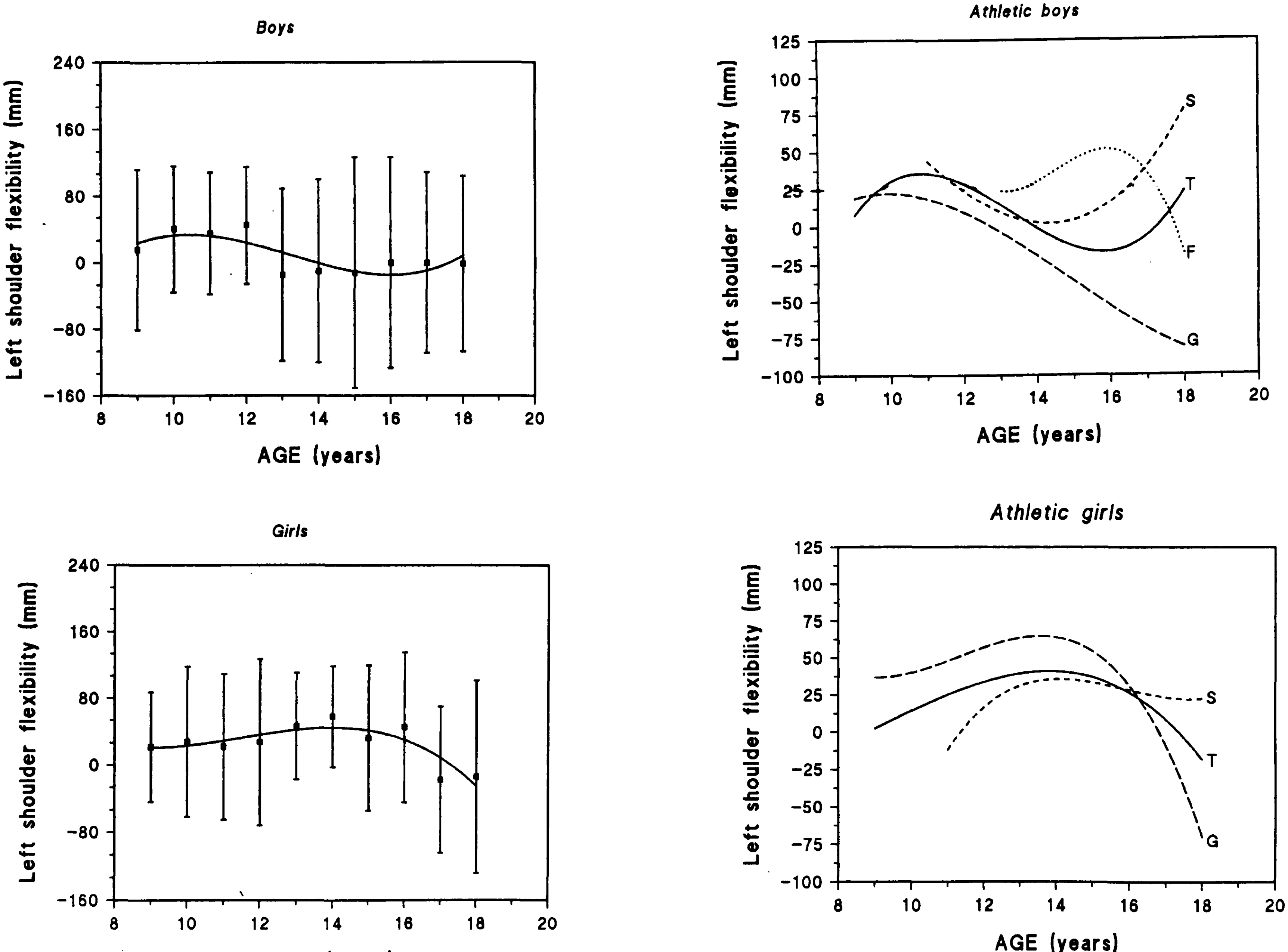
3.B.1. Right shoulder flexibility: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. On the right hand side, only average values in boys and girls divided by sport are given.

Girls

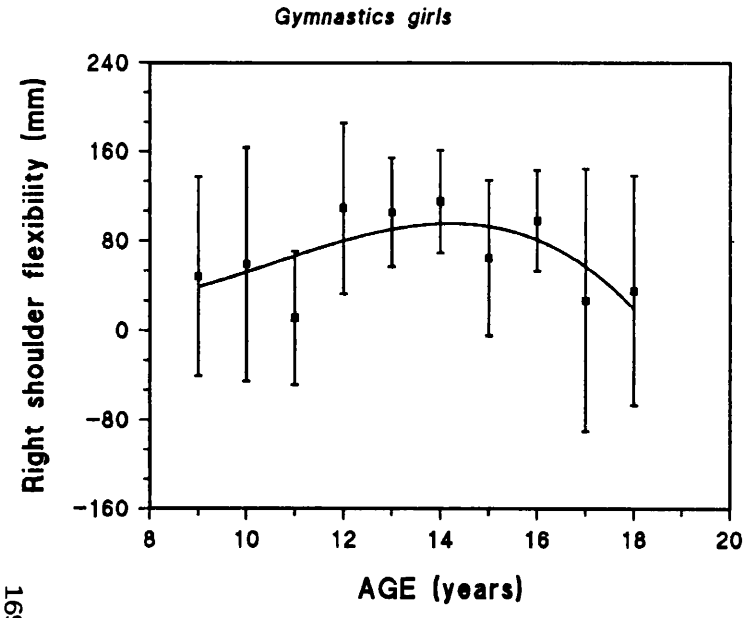


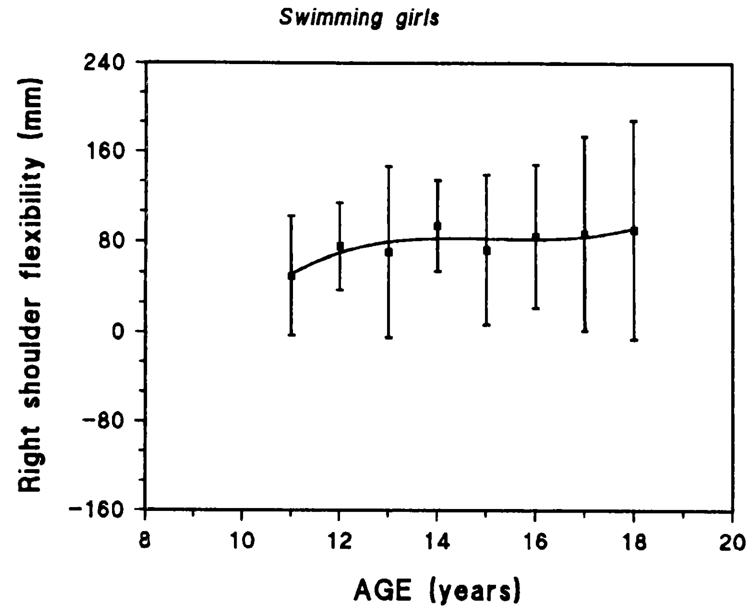
Sporting girls

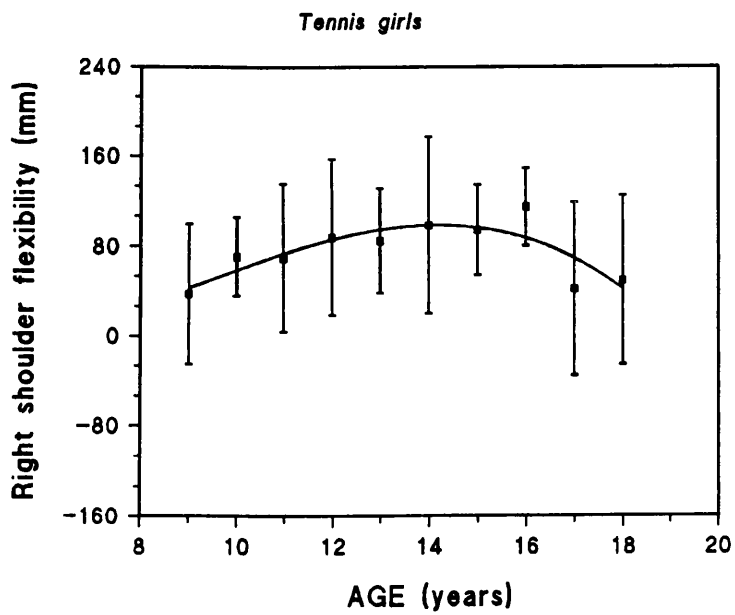




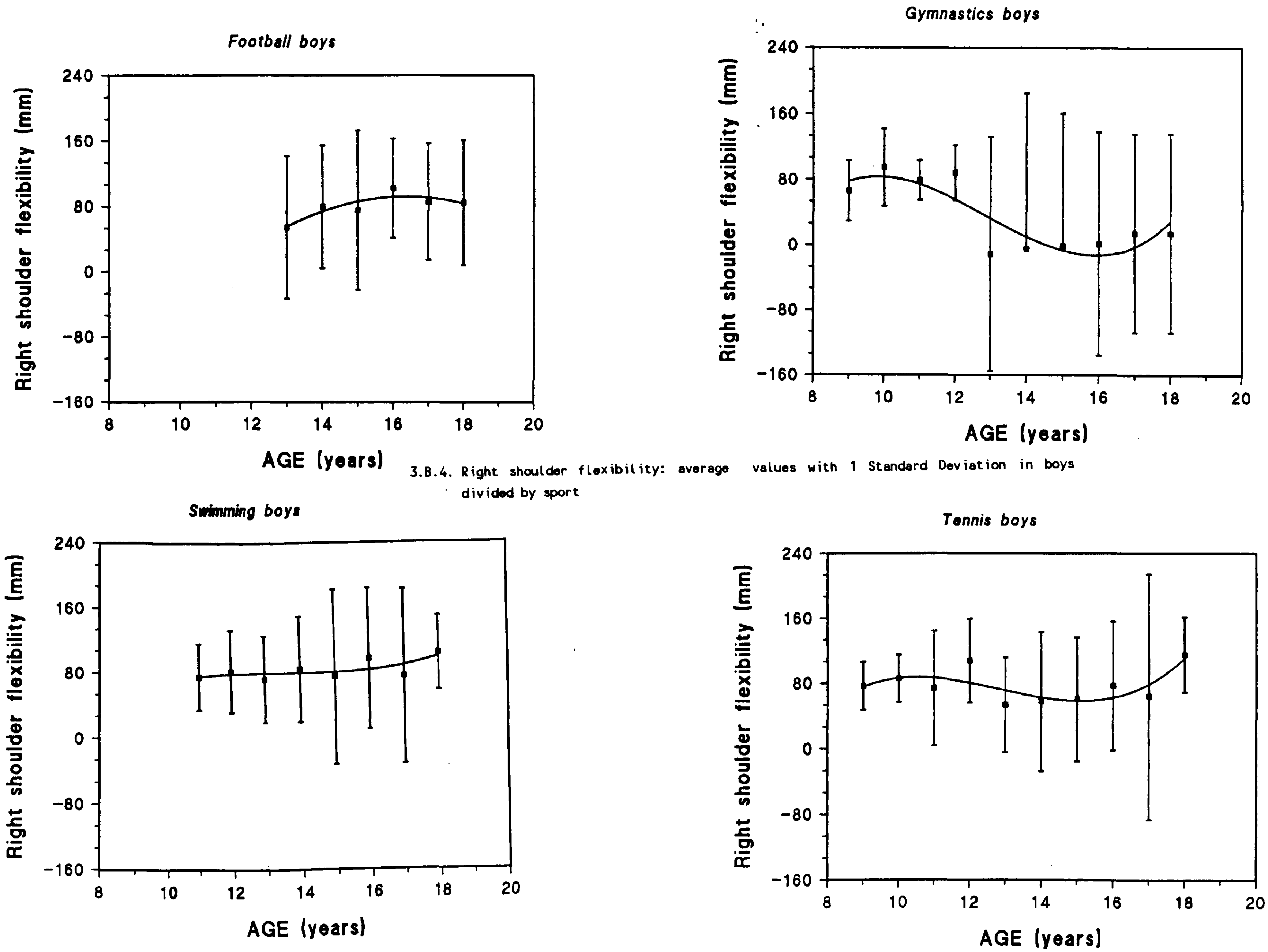
3.8.2. Left shoulder flexibility: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. On the right hand side, only average values in boys and girls divided by sport are given.



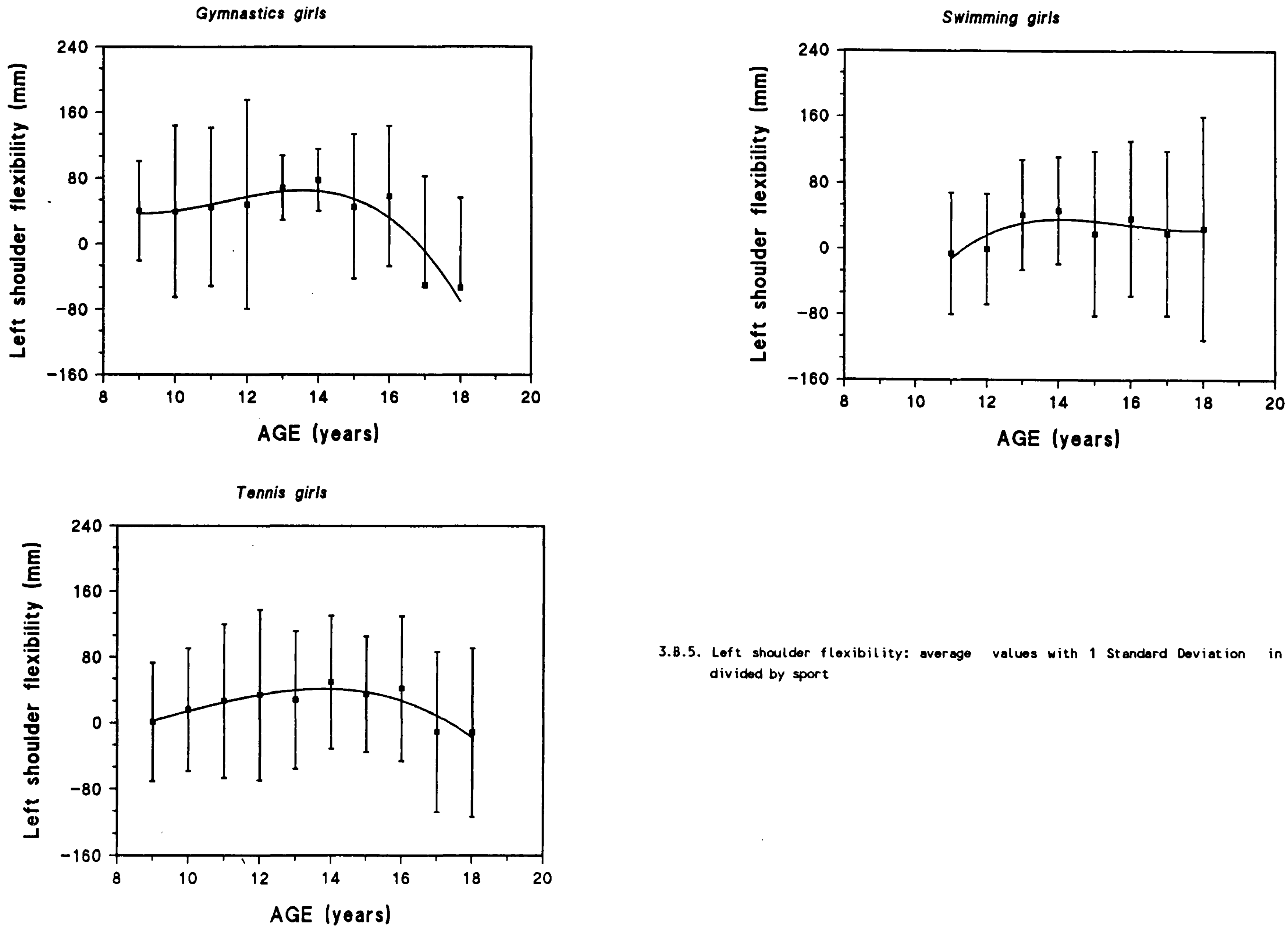




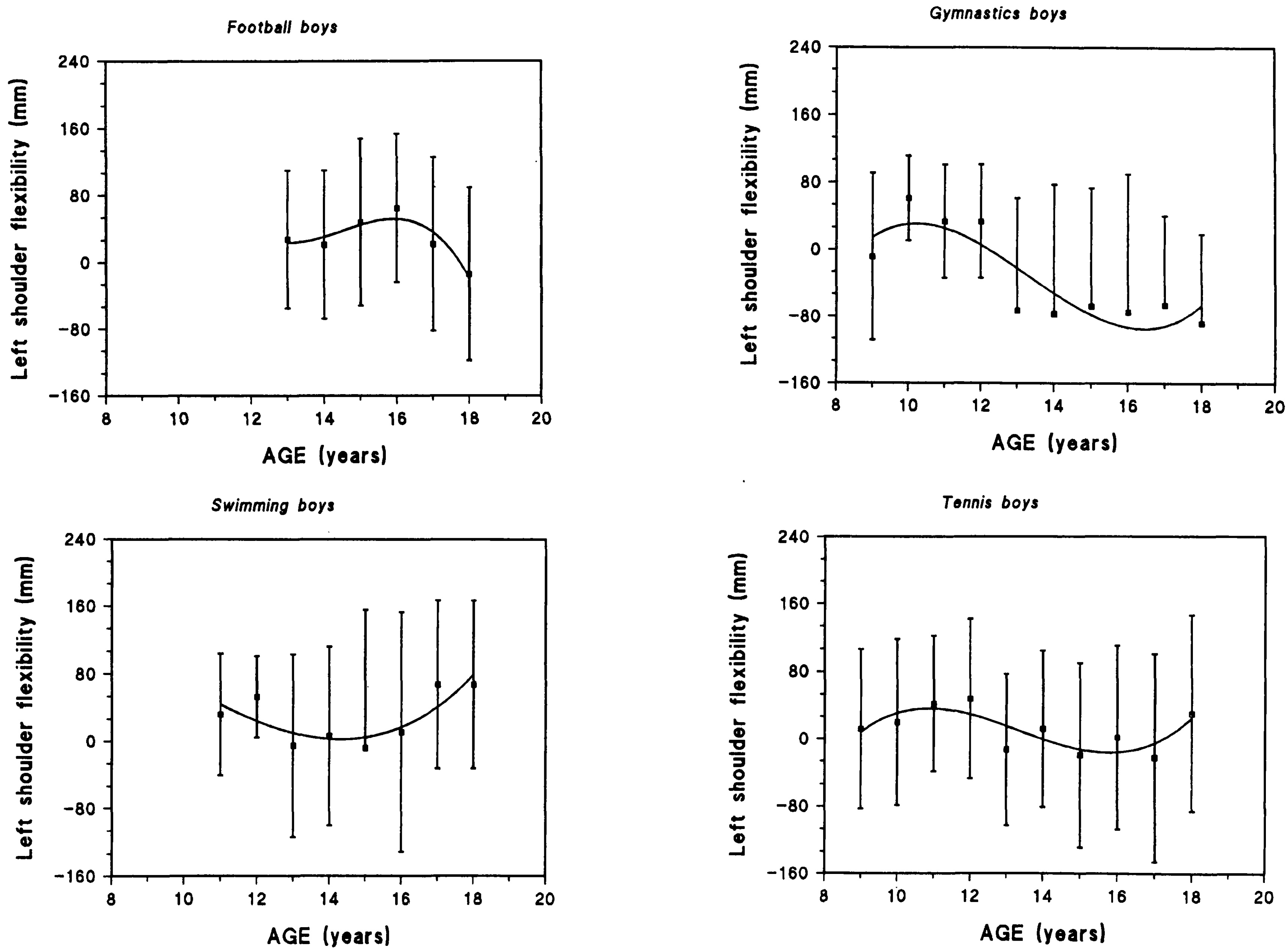
3.B.3. Right shoulder flexibility: average values with 1 Standard Deviation in girls divided by sport



3.B.4. Right shoulder flexibility: average values with 1 Standard Deviation in boys divided by sport



3.B.5. Left shoulder flexibility: average values with 1 Standard Deviation in girls divided by sport



3.B.6. Left shoulder flexibility: average values with 1 Standard Deviation in boys divided by sport

3.B.a.2. Flexibility of the lumbar spine and hamstrings

The average data of the flexibility of the lumbar spine and hamstrings for all the children are presented in Figure 3.B.7. The average values for all sports and for both genders are given in Figures 3.B.8. and 3.B.9.

Analysis of variance of the absolute values showed that girls and boys were equally flexible up to age 12. Between age 13 and 16, girls were significantly more flexible than boys (ANOVA, $p = 0.005$), and the two sexes were not significantly different thereafter. In both sexes, the older groups were significantly more flexible than the younger ones. Boys showed a significant decrease in trunk flexibility at 14 years. No such finding was evident among the girls.

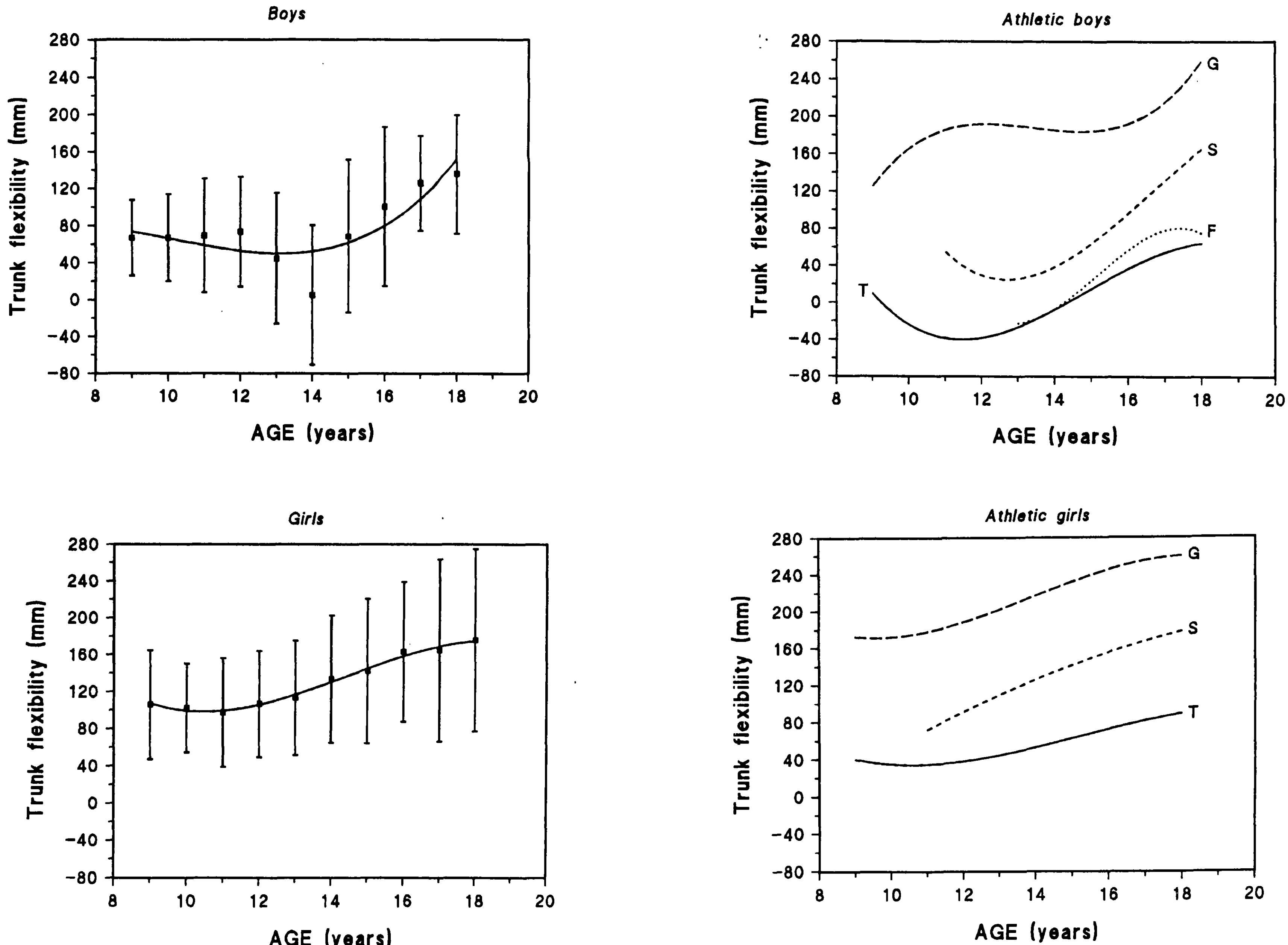
When the four sports were compared, ANOVA revealed that male and female gymnasts were the most flexible of the four groups of athletes, even at a very early age ($p < 0.001$). The average values for trunk flexibility of the four sports were clearly separated, with tennis players and footballers being the least flexible group, followed by the swimmers. Gymnasts were the significantly more flexible at all ages in both sexes (ANOVA, $p = 0.0001$) (Figures 3.B.8. and 3.B.9.).

When the sports were analysed using gender as a covariate, there were no significant effects of age for gymnasts, while swimmers and tennis players were significantly different between age 12 and 16 (ANOVA, $p = 0.01$). By the end of growth, there were no sex differences in the absolute values.

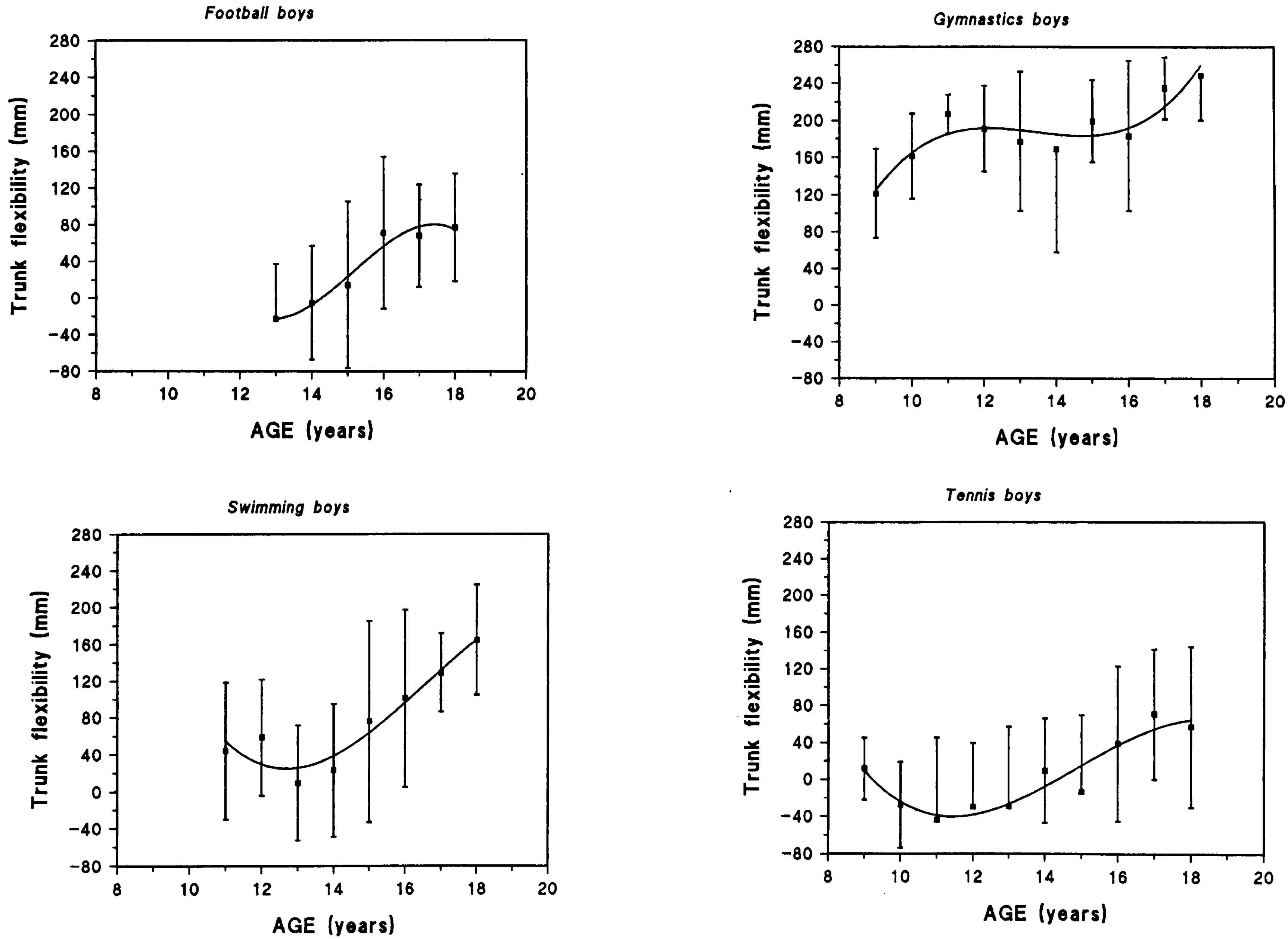
Given the method used to measure trunk flexibility, sub-ischial leg length, cubit length and height were major factors in determining the value measured. ANCOVA was employed to study these covariates. Using this secondary analysis, gymnasts appeared to be significantly more flexible than the other groups (ANCOVA, $p < 0.005$), with tennis-players and footballers being the least flexible. As in the analysis of the absolute values, swimmers fell in between these extremes.

Female athletes in all three sports increased their trunk flexibility with growth (Figure 3.B.9.), and female gymnasts were the most flexible reaching an unadjusted average value 2.5 times greater than that reached by the tennis-players by the end of the study. Furthermore, they were a more homogeneous group at all ages with much less intersubject variability at all ages (Figures 3.B.8. and 3.B.9.). Swimmers were significantly more flexible than tennis-players, but less so than gymnasts (Figure 3.B.8. and 3.B.9.).

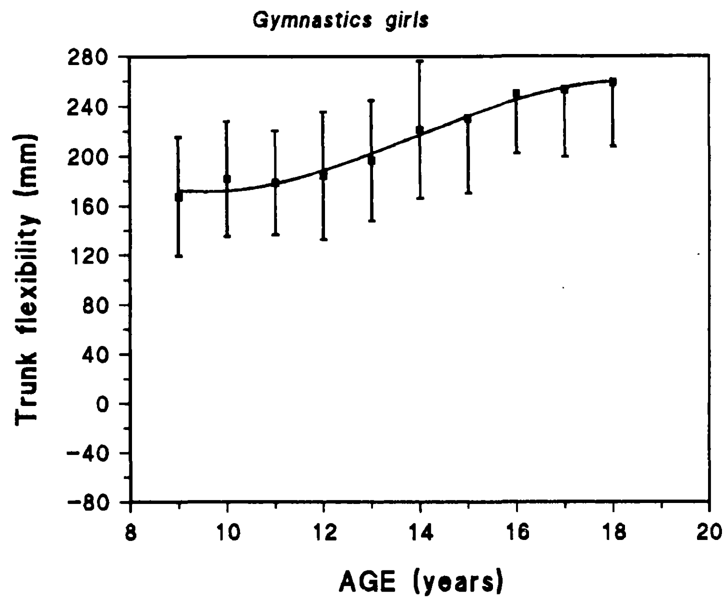
The young male athletes exhibited a somewhat different pattern (Figure 3.B.8.). For example, only the gymnasts and the swimmers were consistently able to reach further down than the plane of the upper surface of the nail of the left hallux. Furthermore, the pattern of performance did not uniformly increase

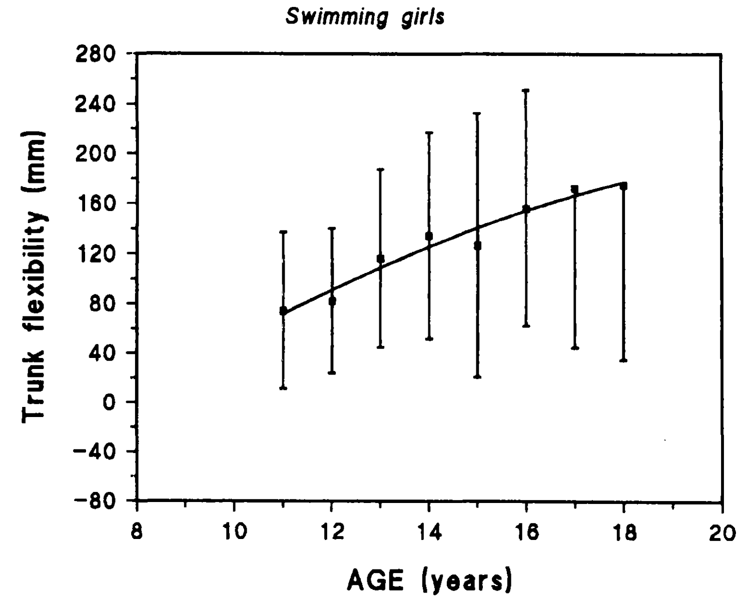


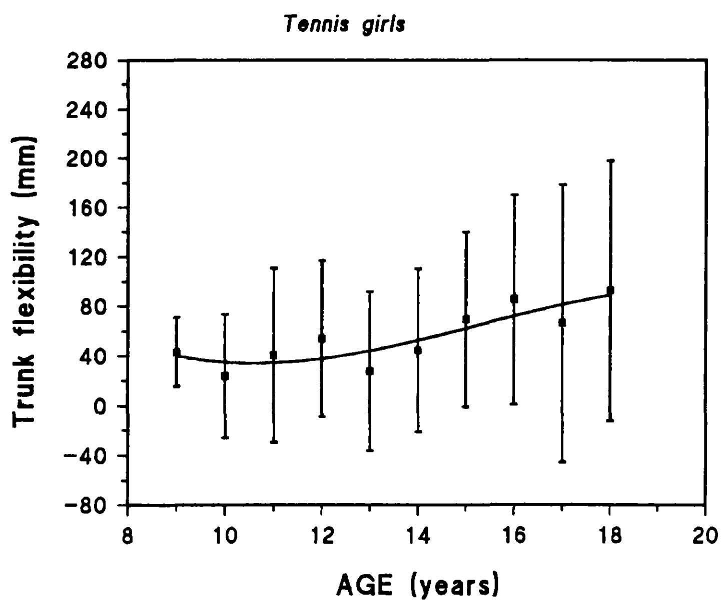
3.B.7. Trunk flexibility: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. On the right hand side, only average values in boys and girls divided by sport are given.



3.B.8. Trunk flexibility: average values with 1 Standard Deviation in boys divided by sport







3.B.9. Trunk flexibility: average values with 1 Standard Deviation in girls divided by sport with age, with swimmers and tennis players showing a temporary decrease in the younger age groups (Figure 3.B.8. and 3.B.9.). Male gymnasts increased their flexibility at a slower rate than swimmers, with a plateau phase between 12 and 16 years (Figure 3.B.8. and 3.B.9.).

When ANOVA analysis was applied to compensate for the effects of subischial leg length, cubit length and height, gymnasts were found to be significantly more flexible than the other groups ($p < 0.005$), with tennis-players and footballers being the least flexible.

3.B.a.3. Flexibility of the hip , adductor muscles and posterior muscles of the thigh complex

Sagittal splits were measured bilaterally, and the results obtained on the two sides were very similar (in all sports and age groups, r at least 0.92, $p < 0.0001$). Although the actual values of the three different splits measured were different, their physiological meaning is very similar, and their evolution was also very similar. Hence, only the results of the front splits will be reported here.

The average data of the flexibility hip joint measured using the front splits for all the children are presented in Figure 3.B.10. The average values for all sports and for both genders are given in Figures 3.B.11. and 3.B.12.

Girls and boys were equally flexible at all ages, and, in both sexes and in all sports, this measure of flexibility increased with age.

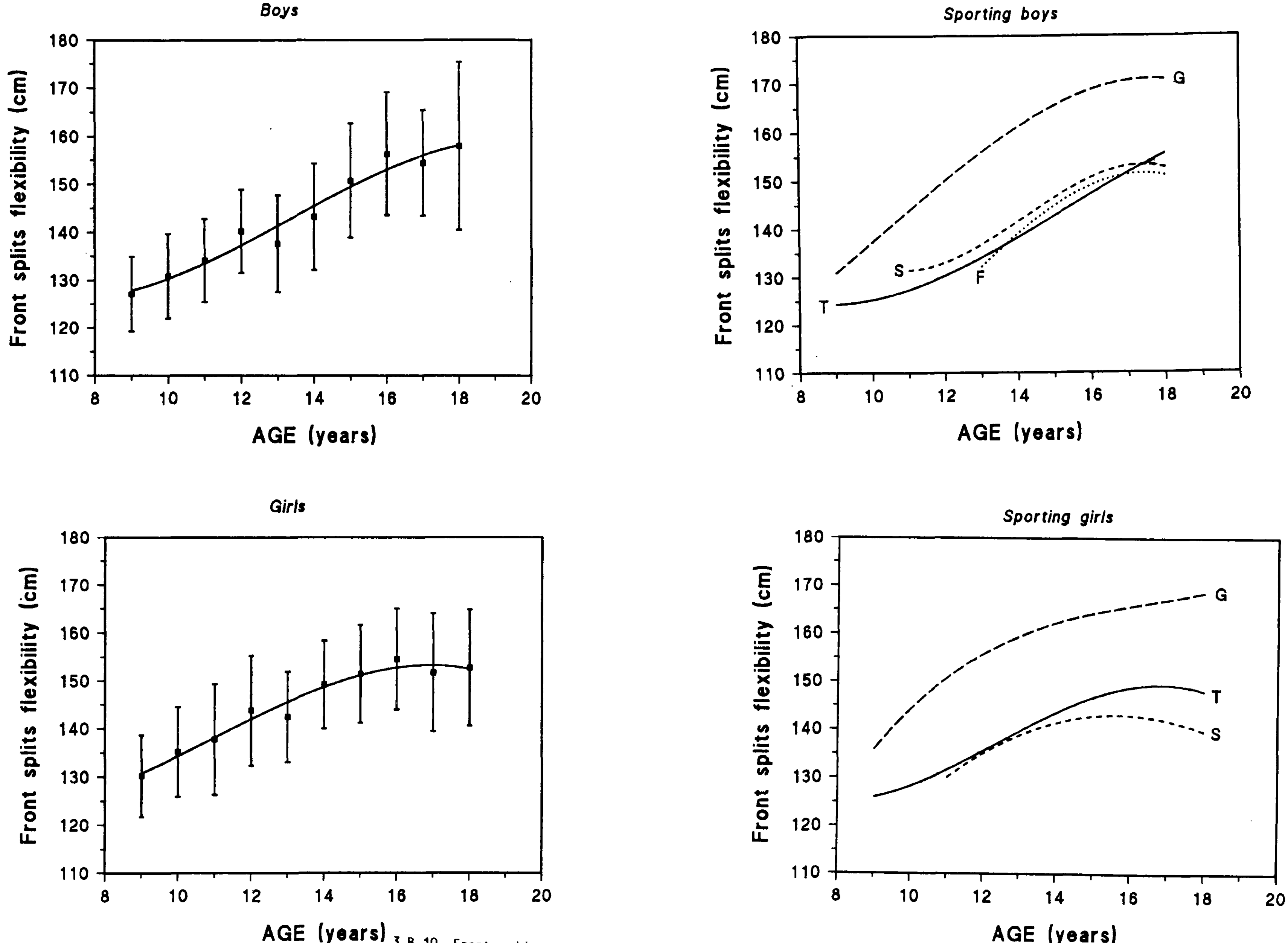
Young gymnasts were significantly more flexible than the other sports from age 14 (ANOVA, $p = 0.0001$), whilst those involved in tennis, swimming and football were not significantly different from each other.

Given the method used to measure hip flexibility, sub-ischial leg length was a major factor in determining the value measured. ANCOVA was employed to study the effect of this covariate. This secondary analysis revealed that gymnasts were significantly more flexible than the other groups (ANCOVA, $p < 0.005$), with tennis-players and footballers being the least flexible. As a group, girls were significantly more flexible than boys after age 14.

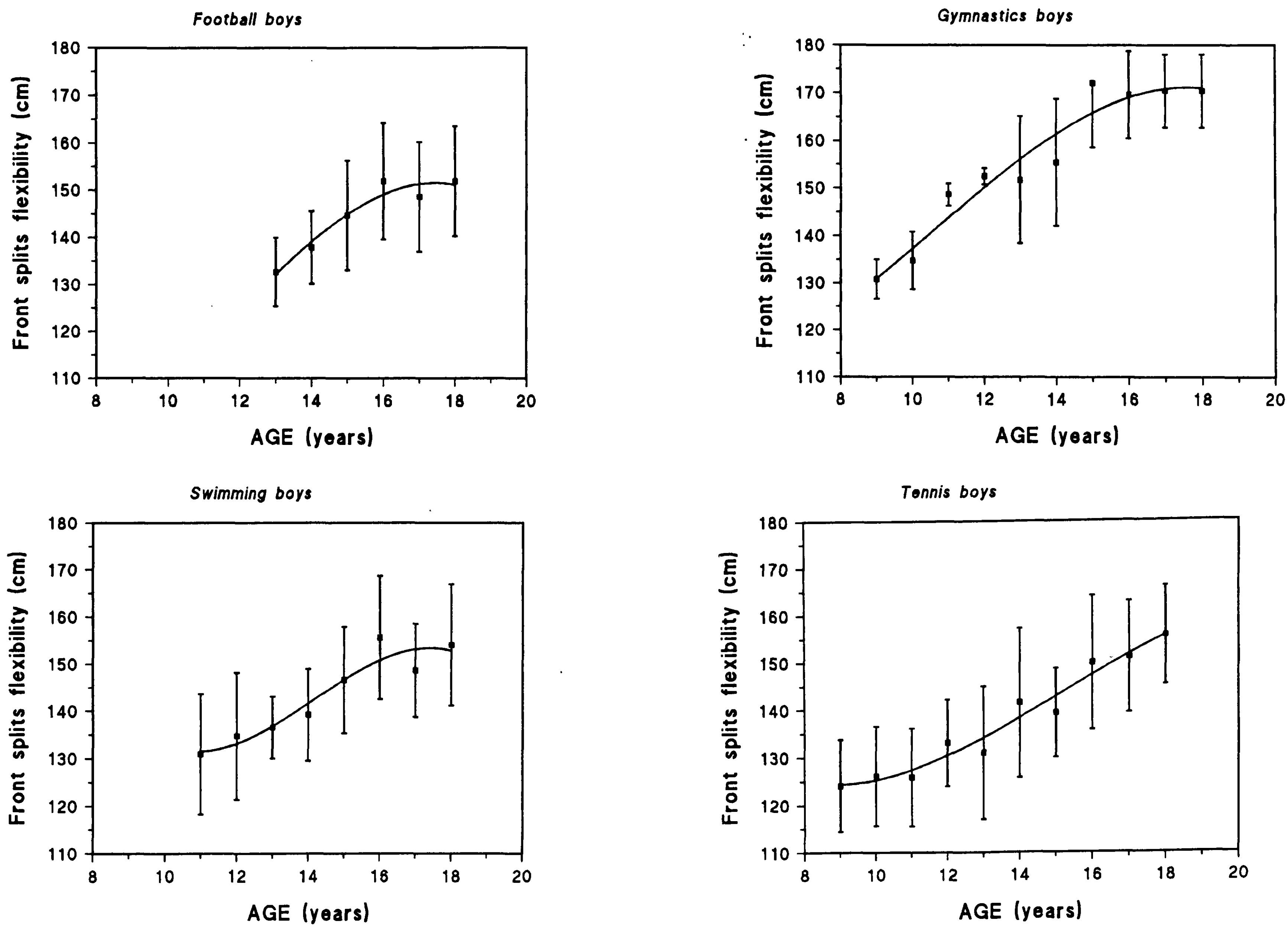
Girl gymnasts showed a greater rate of increase from nine to 12 years of age, followed by a period of plateauing for one to two years, and finally a period of slow increase (Figure 3.B.12.). Boy gymnasts exhibited a plateau from age 16 (Figures 3.B.11.).

Tennis-players and swimmers showed a more linear increase in hip flexibility, with a plateau effect at around 14 years for the girls and 16 for the boys.

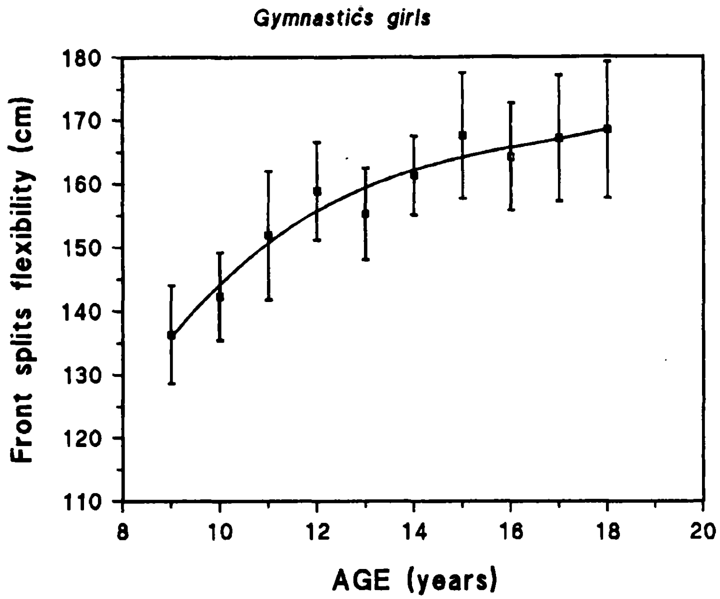
Sub-ischial leg length is a major factor in determining the absolute value measured by this test. ANCOVA was applied in order to compensate for this covariate. Boy and girl gymnasts were by far the most flexible groups ($p < 0.0001$). No additional significant effects were found for age, pubertal stage and training load once subischial leg length was accounted for.

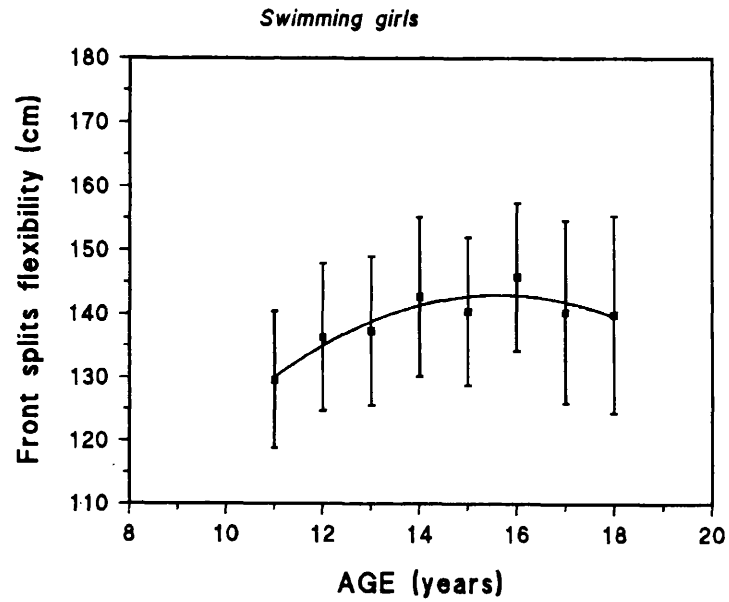


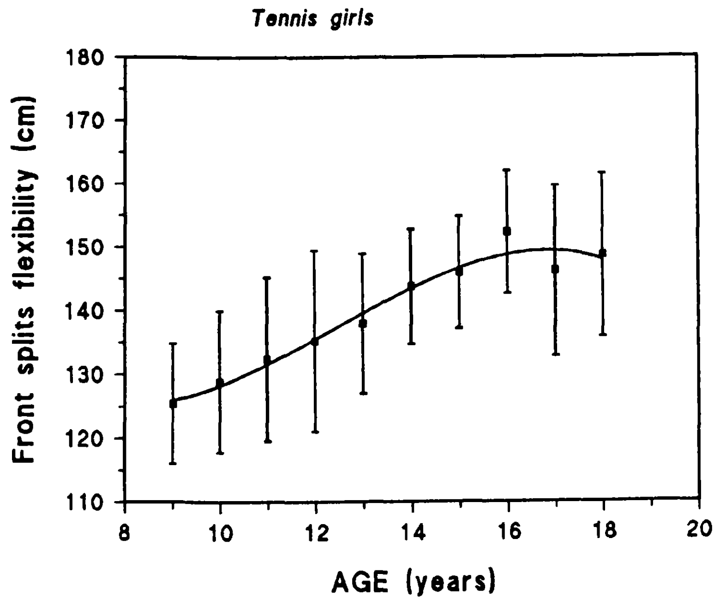
3.B.10. Front splits: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. On the right hand side, only average values in boys and girls divided by sport are given.



3.8.11. Front splits: average values with 1 Standard Deviation in boys divided by sport







3.B.12. Front splits: average values with 1 Standard Deviation in girls divided by sport

From the analysis of the various tests of hip flexibility performed in this study (results shown in Appendixes 4 and 7), the flexibility of the hip joint and surrounding tissues, measured by the different splits, did not appear to be side-specific, and, as expected, a significant effect was exerted by sub-ischial leg length.

3.B.a.4. **RELATIONSHIP BETWEEN THE VARIOUS JOINTS**

The relationship between the flexibility values obtained in the various exercises were studied using linear regression and ANOVA.

When all female athletes were grouped together, trunk flexibility, front and sagittal splits were all highly correlated with each other ($r = 0.58 - 0.90$, $p = 0.005 - 0.00001$) as were the flexibility values of the gleno-humeral joints on the left and right sides ($r = 0.53 - 0.88$, $p = 0.005 - 0.00001$). The flexibility values of both the gleno-humeral joints were also significantly correlated with sagittal and frontal splits ($r = 0.53 - 0.91$, $p = 0.005 - 0.00001$).

When all male athletes were grouped together, trunk flexibility, front and sagittal splits were all highly significantly correlated with each other ($r = 0.56 - 0.80$, $p = 0.005 - 0.00001$), as were the flexibility values of both the gleno-humeral joints ($r = 0.51 - 0.73$, $p = 0.005 - 0.0001$). However, the flexibility values of the gleno-humeral joints were not correlated with sagittal and frontal splits ($r = 0.18 - 0.30$, $p = 0.5 - 0.08$).

To study the possible differences between the genders and the four sports, linear regression analysis and ANOVA were performed, and these data are now presented.

3.B.a.4.1. **GIRLS**

3.B.a.4.1.1. Gymnastics

Trunk, sagittal and frontal splits were highly correlated with each other ($r = 0.51 - 0.77$, $p = 0.005 - 0.00001$), and, although the flexibility of the glenohumeral joints was highly correlated with each other ($r = 0.52 - 0.75$, $p = 0.005 - 0.00001$), they were not correlated with trunk flexibility and splits ($r = 0.17 - 0.24$, $p = 0.3 - 0.06$).

3.B.a.4.1.2. Swimming

Trunk, sagittal and frontal splits showed a similar behaviour to gymnasts ($r = 0.60 - 0.71$, $p = 0.005 - 0.00001$). Flexibility of the glenohumeral joints was highly correlated with each other ($r = 0.54 - 0.81$, $p = 0.005 - 0.0002$), and right shoulder flexibility was highly correlated with trunk, right sagittal and frontal splits ($r = 0.51 - 0.88$, $p = 0.004 - 0.00001$).

3.B.a.4.1.3. Tennis

Trunk, sagittal and frontal splits were highly correlated with each other ($r = 0.55 - 0.72$, $p = 0.005 - 0.0004$). Flexibility of the glenohumeral joints was highly correlated with each other ($r = 0.51 - 0.75$, $p = 0.005 - 0.0001$), and, although glenohumeral joint flexibility on the right side was highly correlated with all other measures (r = 0.51 - 0.71, p = 0.05 - 0.001), this was not so for the left shoulder, which was not significantly correlated with measures of hip flexibility ((r = 0.15 - 0.25, p = 0.06 - 0.05).

3.B.a.4.2. **BOYS**

3.B.a.4.2.1. Football

Trunk, sagittal and frontal splits were highly correlated (r = 0.53 -0.79, p = 0.005 - 0.00001). Flexibility of the glenohumeral joints was highly correlated with each other (r = 0.52 - 0.80, p = 0.005 - 0.0001). Glenohumeral joint flexibility was not significantly correlated with the other joints' flexibility (r= 0.22 - 0.25, p = 0.07 - 0.05).

3.B.a.4.2.2. Gymnastics

Trunk, sagittal and frontal splits were highly correlated (r = 0.63 - 0.92, p = 0.005 - 0.00001). Flexibility of the glenohumeral joints was highly correlated with each other. Glenohumeral joint flexibility was not significantly correlated with the other joints flexibility, except trunk flexibility in the 13 and 14 year olds (r= 0.54 - 0.71, p = 0.005 - 0.00001).

3.B.a.4.2.3. Swimming

Boy swimmers exhibited the same pattern as their female counterparts. Trunk, sagittal and frontal splits were highly correlated (r = 0.59 - 0.89, p = 0.005 - 0.0002). Flexibility of the glenohumeral joints was always highly correlated with each other (r= 0.58 -0.76, p = 0.005 - 0.0001). The flexibility of both shoulders was highly correlated with trunk, right sagittal and frontal splits (r = 0.52 - 0.87, p = 0.005 - 0.0001).

3.B.a.4.2.4. Tennis

Trunk, sagittal and frontal splits were highly correlated (r = 0.60 -0.78, p = 0.005 - 0.0001). Flexibility of the glenohumeral joints was highly correlated with each other (r = 0.61 - 0.79, p = 0.005 - 0.001), although, as in girl tennis players, glenohumeral joint flexibility was not always correlated with the flexibility of any of the other joints.

In summary, the pattern of flexibility exhibited by the various sports was specific. While it is generally perceived that gymnasts are equally flexible in the upper and lower body, this has not been confirmed by the present study. In fact, gymnasts were very flexible in their trunk and their hip joints, while they were clearly lacking in this physical quality in their upper limbs. Swimmers showed a more balanced development in their upper and lower body flexibility. Tennis players showed a possible sports-specific adaptation, in that their right gleno-humeral joint, i.e. of the arm most often found to be dominant, was significantly more flexible than the contralateral.

3.B.b. **FLEXIBILITY: DISCUSSION**

The idea that, to perform at one's best in sport, it is necessary to be able to exploit the whole range of movement of the joints involved in the movement itself is well known. Nevertheless, few systematic attempts have been made to quantify the flexibility of the major joints in the various sports, and no reference data are available for athletic children. This study has shown that some of the ranges of motion are sports specific, and that most of them are influenced by age.

The results are somewhat surprising. For example, the ability to perform better at splits is commonly perceived as a major feature of gymnastics. The data presented demonstrate that, given the wide variability in the children's ability at this particular exercise, the differences between the four sports were not statistically significant up to 14 years of age. On the other hand, the trunk forward bending test may be more specific in this respect. From a talent-selection viewpoint, this could mean that future gymnasts could be better selected by using this latter test rather than the splits, although these are generally perceived as more typical of the sport.

An intrinsic limitation of the tests performed is that they expres linear rather than angular measures. In future, measures of angular excursion should probably be employed, keeping in mind that even these could underestimate the flexibility of the hip joint of gymnasts.

The requirements of the various sports are vastly different, and they may influence the development of certain physical and physiological qualities. However, the differences in body proportions between the various sports should be considered when evaluating flexibility. This was particularly evident in the TOYA Study, when, for example, the young gymnasts were compared with tennis players. When corrected for the relevant anthropometric values, the degree of trunk flexibility shown by the gymnasts became more evident.

At present, given the relatively short duration of the study, no definitive statement can be made about the development of flexibility in the joints surveyed and, given the non-interventional nature of the study, no training suggestions can be given.

This study has shown that when all girl athletes and all boy athletes were taken as a group, the flexibility of both glenohumeral joints was highly correlated with each other, as was the flexibility of the trunk and the hips. In girls, however, flexibility appears to be more generalised than in boys, as upper body flexibility was highly correlated with lower body flexibility, whereas in boys, flexibility of the upper body was independent from that of the lower body.

Gymnastics is perceived as the sport requiring the greatest all-round flexibility. However, when the four sports were compared with each other, it was the young swimmers who showed a greater generalised flexibility.

The relationship between the flexibility of the various joints varied with time. This could be due to several factors. For example, training may be progressively directed towards the development of hip joint rather than trunk flexibility. Alternatively, trunk flexibility may develop before hip joint flexibility. Also, trunk flexibility in the gymnasts may have already been maximally developed in the first year of the study, leaving room for improvement only in the hip joint.

Finally, as the measurement of hip flexibility in this study was dependent on anthropometric characteristics, the different growth of the lower limbs relative to the trunk may play a role in the absolute value of this measurement, with a possible transitory tightening-up effect on the trunk due to overstretch of the soft tissues of the legs. The influence of leg, trunk and arm length on the measurement of trunk flexibility is self-evident (Wilmore & Costill, 1988), and the performance in subjects with extreme differences in arm to leg length or unusual combinations of trunk and arm length may affect the result (Broer & Galles, 1958).

Flexibility in young athletes appears to be joint-specific, in contrast to the generalised laxity exhibited in some medical conditions, and this may have implications in sports injuries, although no such association was found in this study (Chapter 3.A.).

SUMMARY

1. Compared to the other sports, the young gymnasts showed a definite lack of flexibility in the upper limb, while young swimmers showed a greater generalised flexibility.
2. Lower limb and trunk flexibility were highly correlated in the four sports studied.
3. Upper limb flexibility was not significantly correlated with the flexibility of the rest of the body.
4. The tests used may not be the most appropriate to study the flexibility of young gymnasts.
5. When linear measures are used to test flexibility in young athletes, corrections should be made for the anthropometric characteristics of the subjects studied.

3.C. STRENGTH: RESULTS AND DISCUSSION

3.C.a. **STRENGTH: RESULTS**

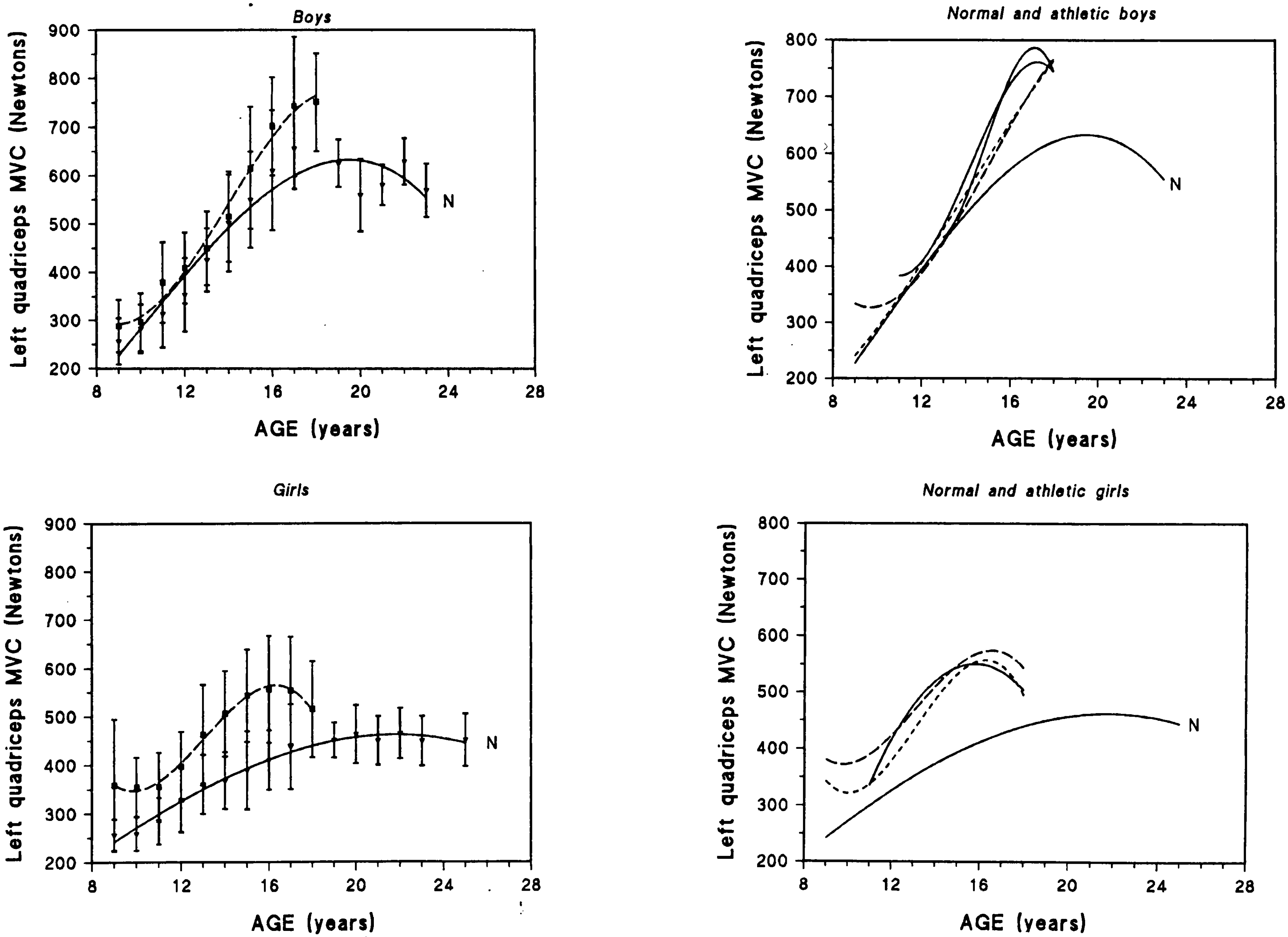
The individual results and the full descriptive analysis of the the isometric strength tests for the knee extensor muscles and the elbow flexor muscles are given in Appendixes 5 and 8, respectively. For simplicity, the results of the primary analysis of the isometric strength exerted by the right side of the body are omitted, as no significant differences between the right and left side were found [ANOVA, p = 0.07 (knee extensors) and 0.06 (elbow flexors)]. Also, anthropometric studies have traditionally been conducted on the left side of the body ('International Agreement for the Unification of Anthropometric Measurements to be made on the Living Subject', International Congress of Geneva, 1912, cited by Cameron, 1984), and recent data on non athletic British subjects have been collected on the left side (Parker, 1989; Parker et al., 1990). The data for the whole population of children will be presented, and, when deemed necessary, the data on each sport will be subsequently presented. The data of the first year of the present study will be compared to the results of a similar study carried out in non-athletic children of the same age using the same apparatus (Parker, 1989; Parker et al., 1990).

3.C.a.1. Knee extensor muscles

The average data of the maximal voluntary contraction strength of the left quadriceps for all the children are presented in Figure 3.C.1.

As a group, girls were stronger than boys at nine years. At 12 years, boys reached the same strength as girls, and the two sexes increased their isometric quadriceps strength in a similar fashion up to the age of 14, when boys started to increase their strength at a faster rate than girls. Maximal isometric voluntary contraction (MVC) strength in girls reached a plateau at 16 years, to decline thereafter, and the average values of knee extensor strength in girls aged 18 were not significantly different from those of girls four years younger. As a group, boys did not show a decrease in the rate of strength increase by the end of the study, and they were significantly stronger than girls from age 16 (ANOVA, $p < 0.003$). The average maximum isometric quadriceps strength in the children involved in the TOYA study was approximately 13% greater for boys and 22% greater for girls than in normal schoolchildren (Parker et al., 1990) (Figure 3.C.1), with the stronger girls (aged 17) well within the range expected for non-athletic boys aged 15 (Parker, 1989).

Within each gender, the average isometric strength of the knee extensors throughout the study was not different (ANOVA, $p = 0.06$). In all sports, girls tended to increase their quadriceps strength at a low rate up to age 12 (Figure 3.C.2.). This was followed by a period of faster increase up to age 15, after which a definite plateau was evident followed by a decrease.

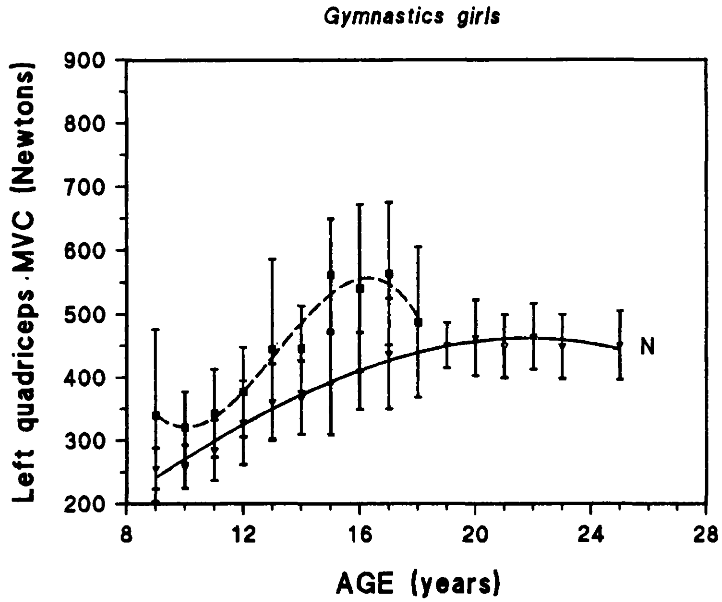


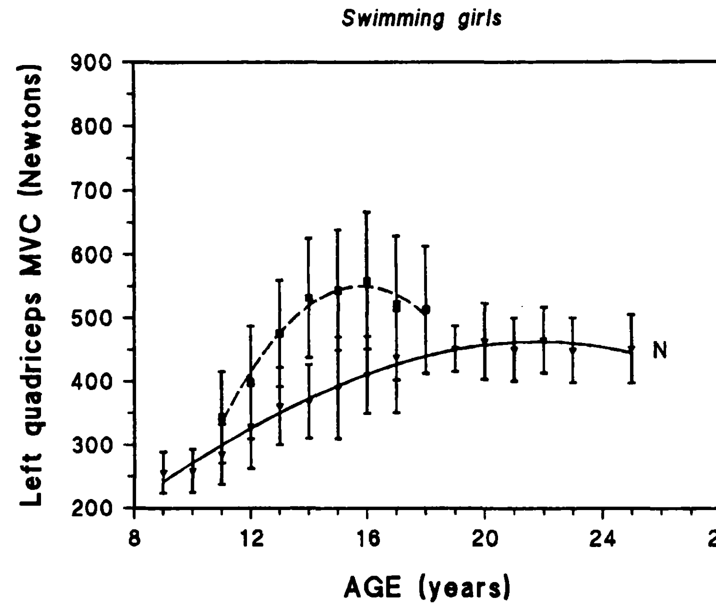
3.C.1. Left quadriceps strength: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. The data on sedentary boys and girls are indicated by a triangle, those on athletic children by a square. On the right hand side, only average values in boys and girls divided by sport are given

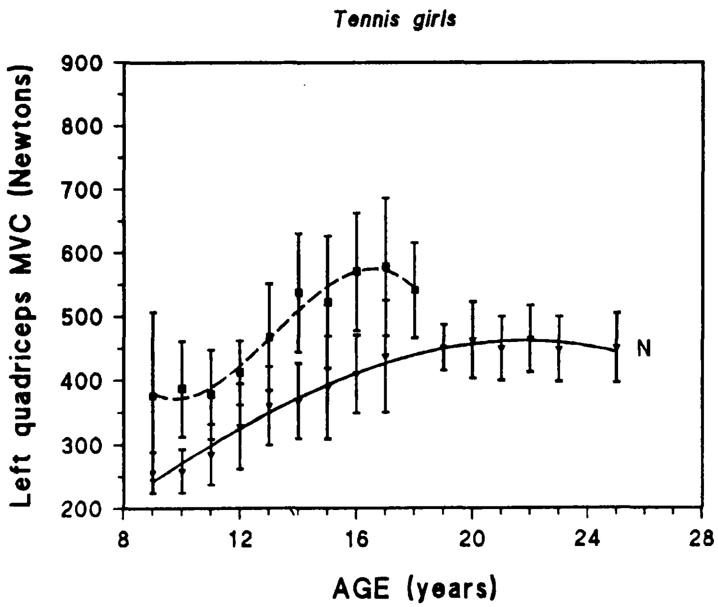
Among the boys (Figures 3.C.3.), the 9 and 10 year old tennis-players were marginally stronger than the gymnasts (ANOVA, $p = 0.03$). They showed a slow increase up to 13 years, followed by a period of faster linear increase up to age 18. Male gymnasts, on the other hand, had a linear rate of quadriceps MVC increase from age nine to 18. While male gymnasts and tennis players did not show a plateau effect by the end of the study, swimmers and footballer players did show such a trend, reaching a plateau at 16-17 years.

ANOVA analysis was performed to study the effects of various variables on the force exerted by the quadriceps muscles. Sport, puberty stage, and height did not exert a significant effect, but age did ($p < 0.0001$).

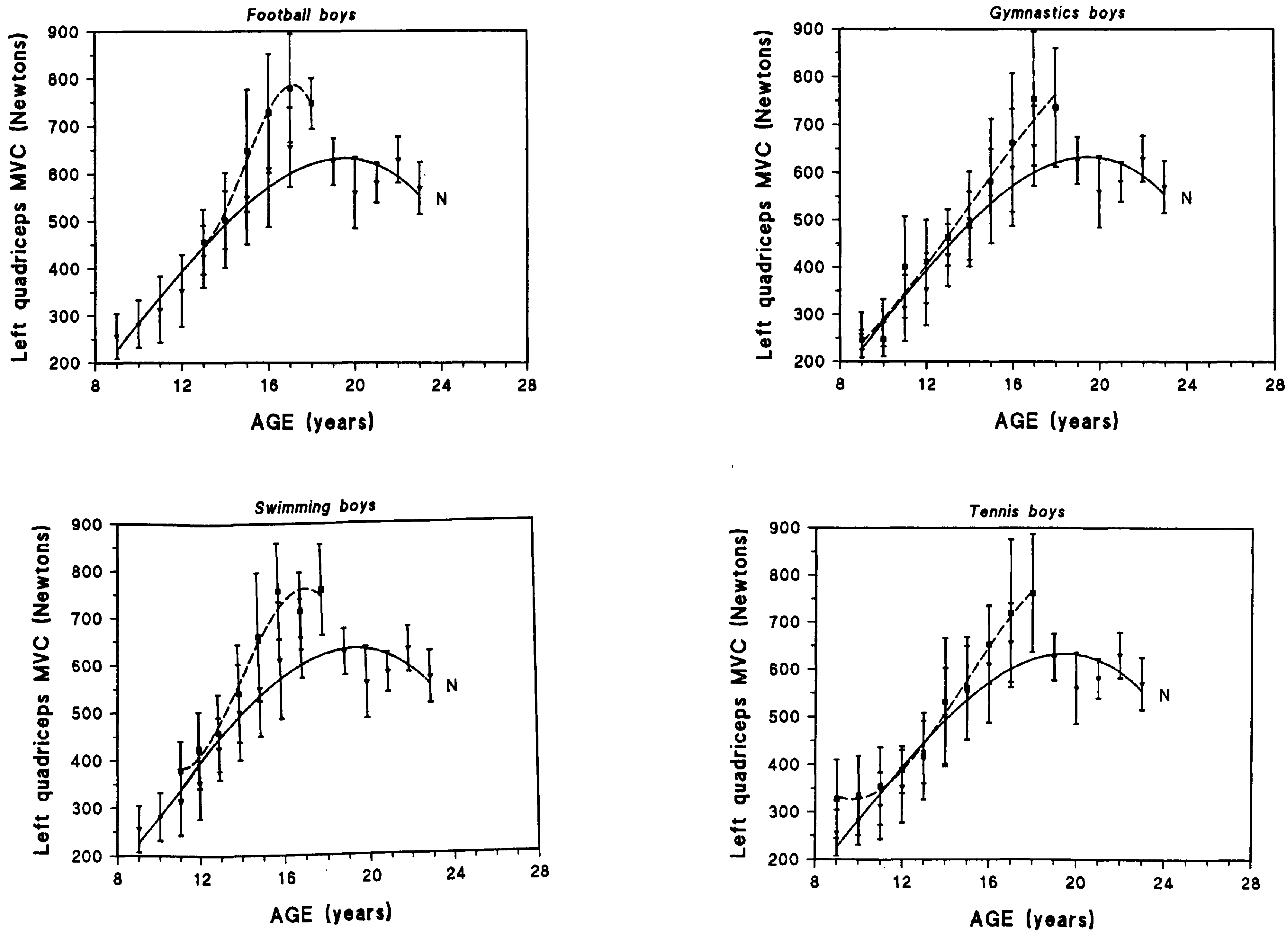
When compared to non-athletic schoolchildren, the children enrolled in the TOYA study were significantly stronger by the end of the study (ANOVA, $p = 0.002$ in girls, $p = 0.0005$ in boys). The time course of these differences was however different, with the athletic girls being significantly stronger at all ages, whereas in the boys this difference only became significant above the age of 15.







3.C.2. Left quadriceps strength: average values with 1 Standard Deviation in girls divided by sport. The data on sedentary subjects are indicated by a triangle, and are connected by a continuous line. Those on athletic children are indicated by a square.



3.C.3. Left quadriceps strength: average values with 1 Standard Deviation in boys divided by sport. The data on sedentary subjects are indicated by a triangle, and are connected by a continuous line. Those on athletic children are indicated by a square.

3.C.a.2. <u>Elbow flexor muscles</u>

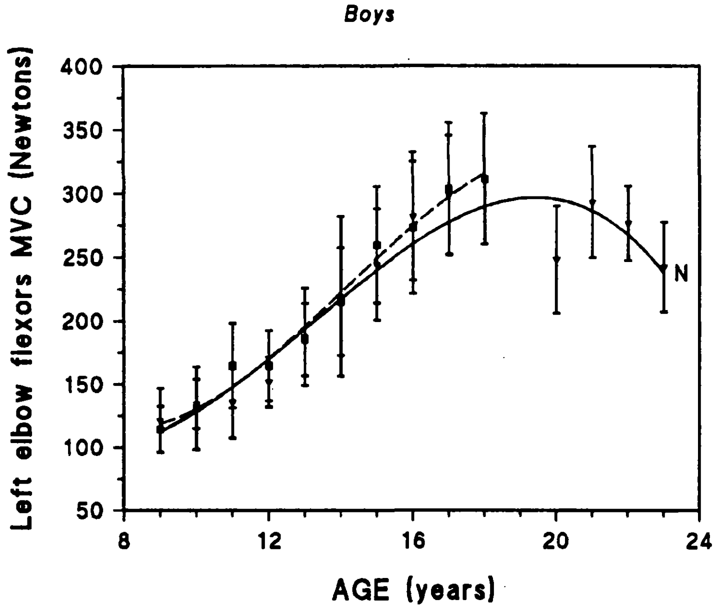
The average data of the maximal voluntary contraction strength of the left elbow flexor muscles for all the children are presented in Figure 3.C.4.

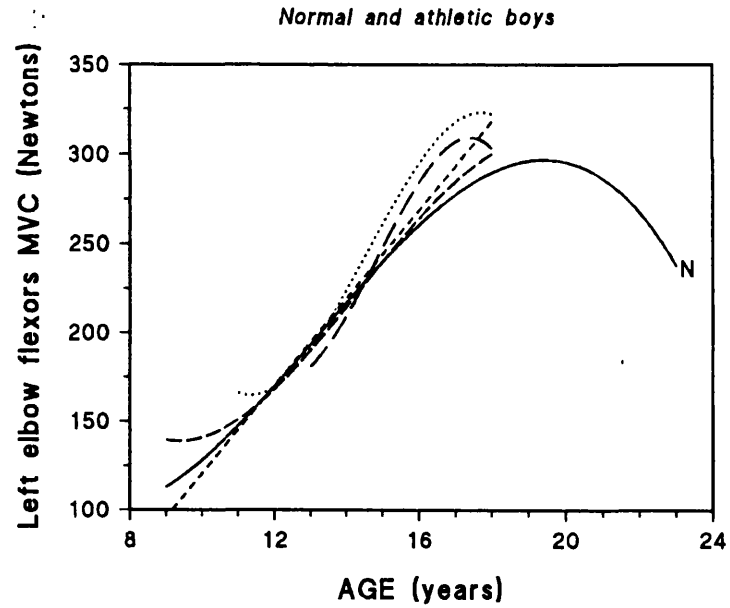
Comparison of the isometric strength of the elbow flexors (Figure 3.C.4.) showed that girls were as strong as boys from nine to 13 years of age, after which time, boys increased their strength at a faster rate, the difference becoming significant by age 14. By the end of the study, boys were stronger than girls by an average of 54%.

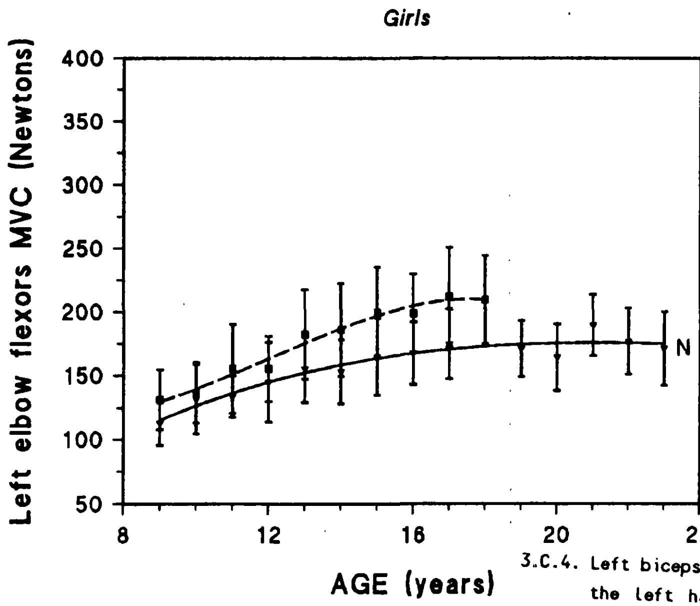
Strength of elbow flexors in girls tended to plateau at around 17 years, while boys were still showing a linear rate of increase at that age. The maximum average strength for the four sports was about 4% greater for boys and 18% greater for girls than the bicipital strength in a group of normal schoolchildren (Parker et al., 1990), less striking differences than for quadriceps strength.

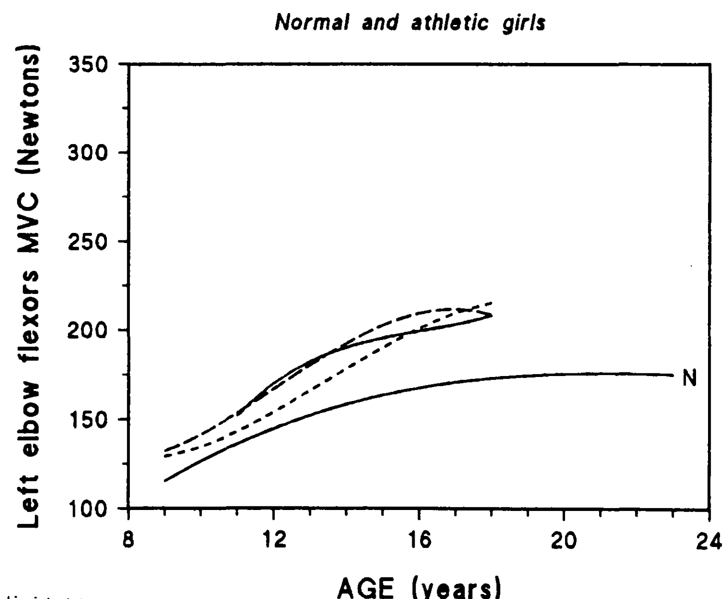
Girls exhibited a faster rate of increase from 12 to 14 years, followed by a period of slower increase from age 15. The three sports were not significantly different (Figure 3.C.5.).

ANOVA was performed to study the effects of various variables on the force exerted by the elbow flexor muscles and for the quadriceps strength. Sport played, pubertal stage, and height did not exert a significant effect, but age did ($p < 0.0001$).









3.C.4. Left biceps strength: average values divided by gender, and by gender and sport. On the left hand side, the average values for boys and girls are given with 1 Standard Deviation. The data on sedentary boys and girls are indicated by a triangle, connected by a continuous line. Those on athletic children by a square. On the right hand side, only average values in boys and girls divided by sport are giv

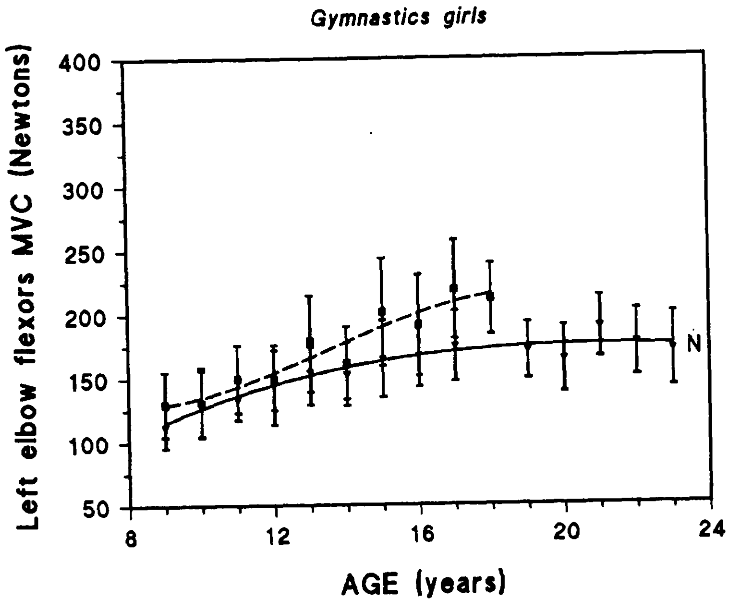
When compared to non-athletic schoolchildren, the girls enrolled in the TOYA study were significantly stronger at the end of the study (ANOVA, $p = 0.03$), while the boys remained within normal limits. Athletic girls appeared to be stronger than their sedentary counterparts throughout, although this only reached significance at 15 years.

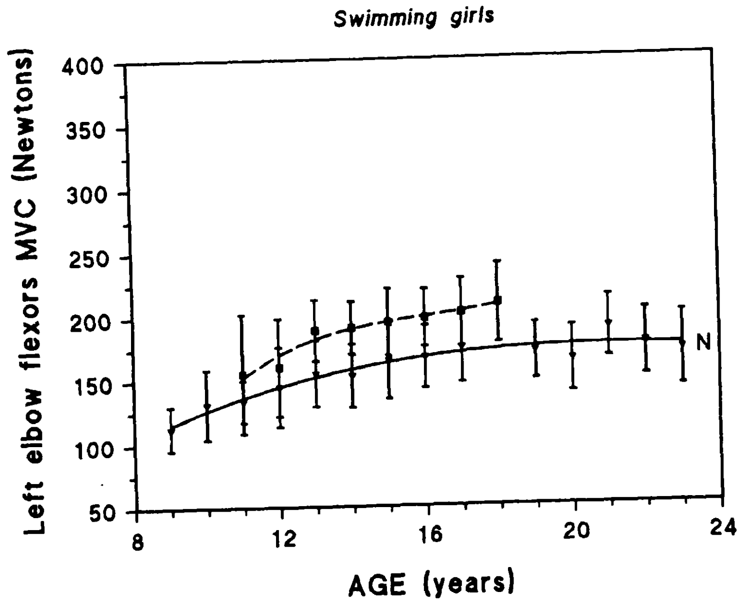
3.C.a.3. Relationship between muscle strength and body weight

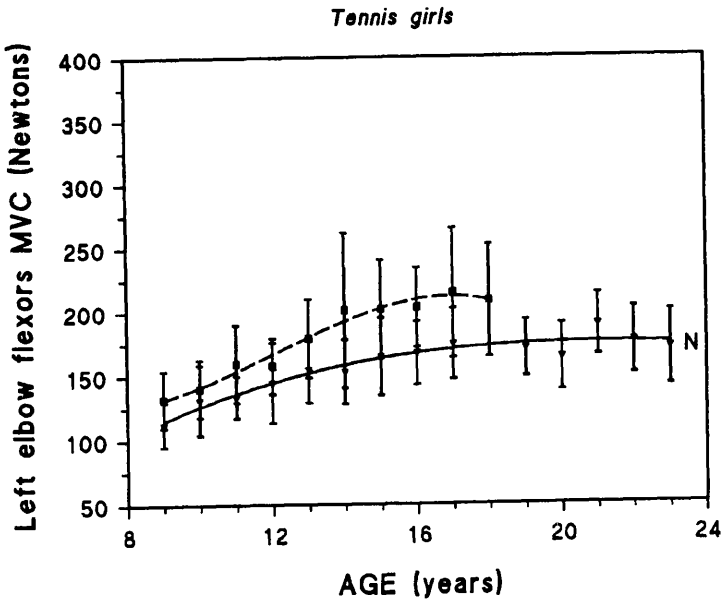
In normal children, maximal isometric voluntary strength exerted by the quadriceps muscle is proportional to total body weight (Parker, 1989). This is easily understood, as the quadriceps are weight-bearing muscles, and the increase in body weight during growth would impose progressively greater loads on the quadriceps during everyday and sporting activities.

This relationship was studied by covariating the data for weight. Young male gymnasts started by being equally strong as tennis players, but, from age 11, they were consistently stronger than the other athletes (ANCOVA, $p = 0.006$ to 0.0001). The other three sports were not significantly different between each other.

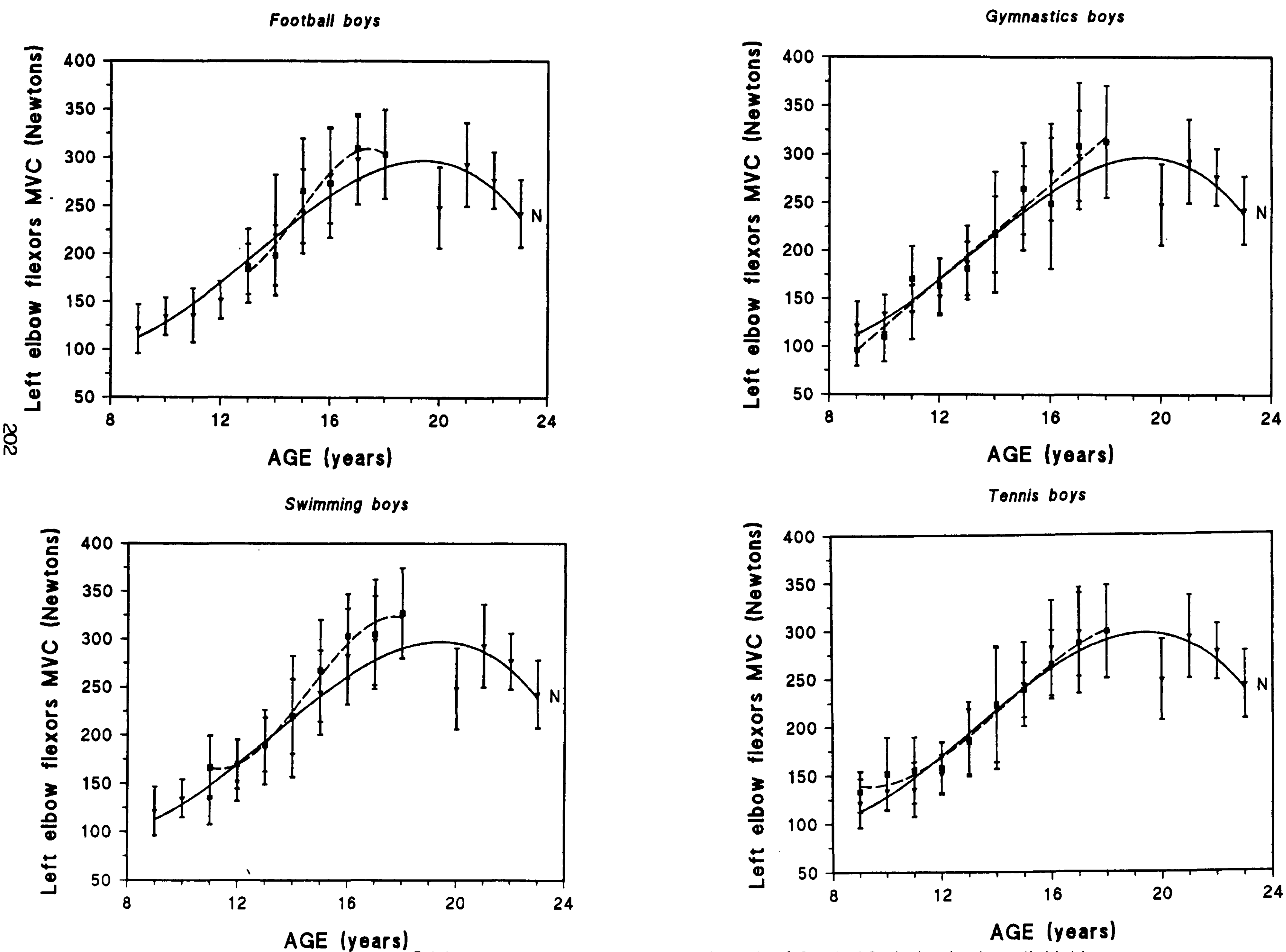
Among the girls, no differences were detectable by the end of the study, although gymnasts and tennis players were significantly less strong at the end of the study than at 9 years (ANCOVA, $p < 0.001$). This was not the case in girl swimmers, who did not show any significant differences between age 9 and 18.







3.C.5. Left biceps strength: average values with 1 Standard Deviation in girls divided by sport. The data on sedentary subjects are indicated by a triangle, and are connected by a continuous line. Those on athletic children are indicated by a square.



3.C.6. Left biceps strength: average values with 1 Standard Deviation in boys divided by sport. The data on sedentary subjects are indicated by a triangle, and are connected by a continuous line. Those on athletic children are indicated by a square

Young male gymnasts had stronger elbow flexors in relation to weight at the end of the study than the other athletes, but this difference was barely significant (ANCOVA, $p = 0.031$). There was no significant age effect when the data were covariated for weight, and the same picture emerged for girls.

3.C.a.4. Relationship biceps strength/cross sectional area of the upper arm

Having considered the effects of body weight, the relationship between force generation and cross sectional area (CSA) of the upper arm was examined, as it has been shown that isometric strength is proportional to CSA of the muscle (Jones & Rutherford, 1997; Maughan, 1984). When the present data were covariated for CSA of the upper arm, the oldest boys were significantly stronger than the girls (ANCOVA, $p < 0.01$), although no significant differences were evident between boys at this age. Of the four sports, gymnastics was the only one in which the bicipital strength covariated for the CSA of the upper arm by the end of the study was significantly greater than at age nine (ANCOVA, $p < 0.005$). No such effect was shown in girls.

3.C.b. STRENGTH: DISCUSSION

Muscle performance was surveyed in the children taking part in the TOYA study by assessing the maximal isometric strength exerted by the knee extensor and the elbow flexor muscles. From the analysis of the absolute strength values, it emerged that boys and girls, in all sports, were of similar strength up to around 11 years, after which the boys increased their strength faster than the girls, and ended up being noticeably stronger than the girls. Isometric strength in the muscles surveyed continues to increase up to 20 years of age in non-athletic male and female subjects (Parker, 1989). Given the nature and the duration of the TOYA study, it was not possible to ascertain whether this was also true for athletes who started their intensive training routines well before puberty. Boys and girls show a different rate of strength increase. For example, both in the upper and lower limb, athletic boys were of similar isometric strength to their non-athletic peers up to 14-15 years, when they tended to diverge from them. Athletic girls, on the other hand, were always stronger than their sedentary counterparts, running at a higher parallel level to them.

The maximal average strength achieved by the children in the study was greater than recently reported in non-athletic British schoolchildren (Parker et al., 1990). Indeed, by the end of the study, athletic girls were on average only slightly less strong than non athletic boys. It is not clear whether this was due to the effects of training or was, to some extent, genetically determined. As the majority of the children in the TOYA study belonged to the higher social classes (see Chapter 2.A.), they could constitute a biased sample. However, the non-athletic population surveyed by Parker et al. (1990) was, on average, on the 75th centile for height and weight, and thus significantly taller and heavier than the average British children. The results obtained could not thus be applied to the mass of non-elite young athletes. The rate of increase in muscle strength in elite young athletes could well be different from that encountered in a control population but, given the relatively short duration of the TOYA study, and the cross-sectional nature of the other recent studies (Parker, 1989; Parker et al., 1990), it is not possible to draw any definitive conclusions on this issue.

The results presented suggest that, at least in some groups of elite young athletes, body weight may exert a significant effect in the increase of muscle strength during growth. Sargeant & Dolan (1986) reported that power output in children, even when standardised for muscle volume, is lower than for young adults. This would suggest that changes in the intrinsic qualities of the muscle tissue may play a significant role in strength development. These changes could be due to change in fibre type composition, changes in intramuscular fat, changes in the lever system through which a muscle acts, and changes in the angle of pennation of the muscle fibres (Jones et al., 1989).

However, the effects of training in this respect are unclear, and it is likely that they would be different according to the sporting activity performed, and to gender. For example, boys taking part in gymnastics and tennis showed continuing increase in strength thoughout the study, girls showed a reduction in the older age groups. It is possible that there were significant differences in training routines and loads among the two sexes. Another possible factor is the effect of growth, or the greater social awareness and peer pressure experienced by the girls during growth.

Of particular interest is the action exerted by sex steroids and growth hormone on the development of muscle strength. It is thought that males have greater muscle development than females because of greater androgen production (Tanner, 1962) and oestrogen production in females may slow down and suppress muscular development: ovariectomised rats reached a greater adult weight than intact female rats (Hervey, 1982). Androgens may also interfere with the uptake of cortisol by liver and muscle (Hervey, 1982). Cortisol has two effects on skeletal muscle: to stimulate repair, and to increase its protein turnover. Androgens may enhance the former and inhibit the latter.

The possible influence of testosterone on muscular strength seems to have a preferential effect on the upper body musculature (Tanner, 1962), but its mechanism of action in this respect is unknown. In athletes, there may be sports-specific differences due to the nature of the sport itself. For example, the upper limb is normally non-weight-bearing but, in gymnastics, it is often used for weight bearing. This may account for the greater load imposed on the limb as compared to the other sports, resulting in greater relative strength. In swimmers, the situation is not clear. This sport is non-weight-bearing, although weight-training and general land-training programmes are being increasingly used.

Typically, increases in muscular strength are induced by low-repetition high force exercises (DeLorme, 1945). Heavy resistance training may produce skeletal muscle hypertrophy (Sale et al., 1987), whereas the increase in strength observed after short-term programmes is thought to be due to neural adaptations and more intensive muscle activation (Moritani & de Vries, 1979). This latter idea is supported by the relative dissociation between increases in strength and muscle fibre hypertrophy (MacDougall et al., 1980) or muscle CSA (Jones & Rutherford, 1987). Strength-trained athletes may also show greater strength relative to muscle CSA than non-athletes (Sale & MacDougall, 1984), and this feature was observed in male gymnasts in the present study.

As a qualitative analysis of the training programmes in which the athletes taking part in this study participate was not undertaken, it was not possible to clearly define how training may have affected the observed differences between the various sports. However, it was likely that different loads were imposed on the specific muscle groups considered. For example, footballers often practise weight-training although they mainly use the lower limbs in their sport. Gymnasts make their upper limbs weight-bearing, imposing on them a variety of eccentric and concentric loads. Swimmers are obliged by the medium in which they train to undergo a kind of continuous isokinetic muscle contraction (Astrand & Rodhal, 1986).

Finally, tennis is characterised by a series of short bursts of possibly anaerobic activity, during which maximal muscular contractions occur. The different requirements of each sport imply a different pattern of activity with different neuromuscular activation (Astrand & Rodhal, 1986), eventually resulting in different neural adaptation (Moritani & deVries, 1979). On the other hand, the question as to whether genetic factors underlie the observed differences in various groups of athletes is as yet unresolved.

SUMMARY

1. Intensively trained athletic children appeared to to stronger than normal schoolchildren.
2. The average maximal isometric strength exerted in both upper and lower limbs in the four sports was remarkably similar.
3. When the results were covariated for weight, gymnasts were significantly stronger than the other athletes.
4. When the results were covariated for the cross-sectional area of the upper limb, no age effect was found in the development of elbow flexor strength in athletic girls. On the other hand, in male gymnasts bicipital strength was significantly increased from the beginning of the study when this was covariated for the cross sectional area of the upper arm.

4.A. CONCLUSIONS

4.A. CONCLUSIONS

It appears that elite young athletes are at risk of sports injuries, but these injuries are not particularly serious, and do not occur with the same frequency as in non-elite youngsters undergoing intensive training. On the other hand, even in this present group of elite athletes, the children who spent less time training, footballers and tennis players, were at risk of a significantly greater number of injuries than the more intensively trained children practising other sports.

This suggests that coaches, parents and the children themselves may have to be prompted not to rely on pure performance, but on training and practice, in order to compete at high level. It can be hypothesised that the sample of children taking part to the TOYA Study was biased, having a musculo-skeletal system intrinsically more resistant to injuries. One of the possible flaws of the study is that injuries were identified retrospectively and were not confirmed by immediate medical examination. More injuries could have been detected if the children had been studied prospectively, and clinical examination had been supplemented by, for example, radiography or ultrasound scanning.

Isometric strength in these athletes, although higher than in normal school-children of comparable age, was within previously described limits. The differences between the four sports were not accounted for by the amount of training, or anthropometric characteristics (except weight), and were probably sports-specific, as were the differences in flexibility. During the process of growth, quantitative and qualitative changes probably contributed to the increases in sporting performance.

It is still not possible to quantify the effects of specific training on the various physical and physiological characteristics of growing elite young athletes. In future, more comprehensive studies could be perfomed to elucidate the effects of intensive training on young athletes. Although expensive, time consuming and at times tedious, the prospective design should be applied in large number of children for longer periods than the one performed in this study. A difficult task would be to identify the variables to study and to devise new tests which are valid and specific to young athletes, because some of them may not be discriminatory enough if the physical or physiological quality is to be studied in elite performers.

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