Mediating variables in the relationship between 2D: 4D digit ratio and sports achievement rank

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Declaration

I hereby declare that the work reported in this thesis has not been previously submitted for any degree. All material in this thesis is original except where indicated by reference to other work.

This study investigated the extent to which 2D: 4D digit ratio, mental rotation ability and the personality variables of social-potency, achievement, harm-avoidance and control are effective predictors of achievement rank in team sports and also whether the relationship between digit ratio and rank can be explained by the influence of these predictor variables. The extent to which these correlations are moderated by participant sex and sport contact intensity was also investigated. Basketball, football and rugby players (ranging in standard from 'social' to 'international' level) as well as non-sport participants were recruited from four universities in the north-east of England. Each participant completed an inventory of personal details (such as age, weight, height and ethnicity), a personality inventory and a mental rotation test. Right-hand photocopies were taken to allow calculations of the participants' digit ratios. Non-sports players' scores did not significantly differ from the sports participants, with the exception of digit ratio and weight. Digit ratio, social-potency, height and weight were found to be significant discriminators of the sports players' rank and sex. The influence of digit ratio upon athlete achievement rank was found to be highly independent of the other predictor variables. The 'years played' and 'hours spent training/playing per week' of the sports participants, were found to be the best predictors of athlete achievement rank as well as having the greatest mediating influence on digit ratios correlation with rank, of all the other variables (digit ratio was still significantly associated with rank after removing these effects).

Chapter 1:
Introduction and review of the literature on 2D:4D digit ratio

Introduction to the Thesis

Within competitive sports, and in particular top-level sports, athletes are constantly evolving; they are becoming faster, stronger, more agile and more skilled. The differences among elite athletes' performances are now far less extreme because technologies and training practices at the highest levels are now relatively similar with most athletes training to their physical limits. Many modern professional competitors have the capacity to win a single contest or championship. In the modern Olympic games, the difference between a gold medal and not even a place on the rostrum within a sprint final can be a matter of milliseconds! Even if a competitor has the necessary skills, training and motivation, they are unlikely to turn in a personal best performance at every competition. Coaches are now striving to gain that extra edge for success in two particular areas among others: a) They are now focusing more and more upon the psychology of athletes to attain their optimum and most consistent performances, as many have reached saturation levels in terms of physical preparation. b) Resources are being directed to early talent-identification and subsequent development programmes in order to find children with great potential at the youngest possible age and to train them at the highest level so as to develop them into super-athletes.

I will begin this thesis with separate literature review chapters on the three main topics of this research: 2D:4D Digit Ratio (chapter 1), Personality/Sports Research (chapter 2) and Visual Spatial Ability (chapter 3). These literature review chapters will lead on to the final chapter of this introduction: The proposal of the current investigation, design and hypothesis (chapter 4).

What is 2D: 4D digit ratio?

This current investigation is concerned with the ratio between the length of the second finger or index finger in relation to the length of the fourth finger or ring finger, which is referred to as 2D: 4D digit ratio or simply 2D: 4D. Measurements are taken from the central point of the basal crease to the central point of the tip of both fingers using digital callipers and then the second digit score is divided against the fourth digit score for the final measure. Regarding the specific measuring technique and apparatus used, further information is provided in the method section of this study.

"In the human hand the 2^{nd} and 4^{th} digits present a pattern of approximate symmetry around the central axis of the third digit, However there is a considerable variation in the ratio of the length of the 2^{nd} digit to the 4^{th} digit (2D: 4D). Many individuals have longer 2^{nd} digits than 4^{th} and many have longer 4^{th} digits compared to 2^{nd}" (Manning, Scutt, Wilson and Lewis-Jones, 1998 pp1). There is abundant evidence suggesting that the former ratio is more common in females and the latter more common in males (Manning, 2002b; Phelps, 1952).

Why measure digit ratio and why are there sex differences?

2D: 4D digit ratio is regarded as a physiological marker for the prenatal concentrations of the sex hormones testosterone and oestrogen, which organise the architecture of the body and the brain and the distribution of hormone receptors (Manning, Bundred, Newton and Flanagan, 2003). When testosterone increases in later life, it activates these pre-existing structures. Because prenatal testosterone is stable, it follows that it can be adequately measured at any time as opposed to blood or saliva testosterone, which fluctuates diurnally and can be significantly influenced by many variables (Olweus, Mattsson, Schalling & Low,1988; Ross, Bernstein, Judd, Hanisch, Pike, & Henderson ,1986). This was first indicated by the clear sexual dichotomy of 2D: 4D, with men having lower ratios and women having higher ratios, which coincides with the occurrence that women, prenataly, have a higher ratio of oestrogen to testosterone while men prenataly have a higher ratio of testosterone to oestrogen and therein lies the significance of digit ratio: A low digit ratio is correlated with high prenatal testosterone and low oestrogen and a high digit ratio is correlated with low prenatal testosterone levels and high oestrogen levels. The specific reason for this sex hormone influence upon 2D: 4D digit ratio is that: "testosterone appears to stimulate the prenatal growth of the fourth digit while oestrogen promotes the growth of the second digit" (Manning 2002b, pp24).

Further evidence for this digit specific relationship with prenatal sex hormones comes from the finding that the fourth finger appears to be more sensitive to androgens than the second; this is evident because it is far more likely to have hair growing on the middle segment (phalanx 2) of it. Hair on this same segment of the second finger is far less likely. Hair growth in this position is dependent on testosterone and more specifically a metabolically active form of testosterone, dihydrotestosterone (DHT). Winkler and Christiansen (1993) found hair growth on the phalanx 2 of fingers to be positively related to testosterone. The phalanx 2 hair growth is the least on the second finger of the whole hand which suggests that it is less sensitive to testosterone and more sensitive to oestrogen.

Manning, a highly prominent researcher in this field of digit ratio/androgen relationships has found further evidence for this proposed relationship, which among many other studies was confirmed in his collaborative 1998 study (Manning, Scutt, Wilson, & Lewis-Jones, 1998). This study demonstrated that, after adjusting for height, weight and age (as larger men have more testosterone and older or obese men have reduced testosterone) high free testosterone and low free oestrogen concentrations were significantly correlated with low digit ratio in a hundred and thirty one male participants. This finding also indicates that prenatal sex hormone concentrations are associated with free sex hormone concentrations. It is worth noting that these participants were patients at an infertility clinic, which may possibly be associated with abnormal hormone levels, and so may not be valid representations of the general population.

What is the biological occurrence that links 2D: 4D to prenatal sex hormones?

A foetus is exposed to prenatal testosterone from two sources: The foetal testes and the adrenal glands. The main source of prenatal oestrogen comes from the placenta and the adrenal glands through the aromatase conversion of testosterone from the maternal blood stream (George, Griffin, Leshin and Wilson, 1981). The developmental differentiation of foetal gonads is greatly influenced by these foetal sources of steroids (Lording and De Kreter, 1972). The differentiation of the foetal gonads is controlled by the homeobox or Hox genes (Zakany and Duboule, 1999). In particular the posterior-most Hox-d and Hox-a genes are strongly expressed in the urino-genital system including the gonads, however these genes are also required for the growth and differentiation of digits and toes (Csatho, Osvath, Bicsak, Karadi, Manning and Kallai, 2002). This common control of the differentiation of digits and gonads has allowed aspects of gonadal functions such as the production of testosterone and oestrogen to affect the development of the digits.

Further evidence to support this process and relationship is the occurrence of the disorder 'hand-foot-genital syndrome' which causes anatomical defects in both the digits and genitalia of humans and has been proven to be caused by the mutation of the Hox-a gene (Mortlock and Innis, 1997). Supplementary evidence has also come from mice studies where deregulations of Hox-d expression have been shown to alter the relative lengths of digits and affect the growth of the genital bud (Kondo, Zakany, Innis and Duboule, 1997; Peichel, Prabhakaran and Vogt, 1997). It can thus be concluded that the sharing of causal factors in digit and gonad differentiation strongly suggests that patterns of digit formation reflect testis function and, therefore, prenatal sex hormone concentration.

The relationship between 2D: 4D digit ratio and foetal testosterone/oestrogen is difficult to measure directly. A precise method of studying these proposed correlations would be to take the hormone samples from the amniotic fluid of foetuses and examine correlations between the testosterone/oestrogen concentrations and the postnatal childhood digit ratio. However because of the invasive nature of such a technique, such tests have not been performed (at least to the knowledge of the current investigation).

In summary, Manning (2002a) proposes that a low 2D: 4D digit ratio (the fourth finger longer than the second) acts as a marker for a uterine environment high in testosterone and low in oestrogen, and such a ratio is most often seen in males. Conversely a high 2D: 4D ratio may serve as a marker for a uterine environment low in testosterone and high in oestrogen, of which is most often found in females. Thus digit ratio is sexually dimorphic.

It should be stipulated that measures of 2D: 4D may not be representative of absolute concentrations of prenatal hormones. Variation in digit ratio has also been attributed to differences in the distribution, frequency and sensitivity of androgen and oestrogen receptors (Tanner, 1990). Therefore 2D: 4D can be more specifically said to represent the body's sensitivity and thus capacity to utilise prenatal concentrations of testosterone and oestrogen. Theoretically, if an individual has a higher prenatal concentration of one of these sex hormones than is represented by their digit ratio, their body has only been receptive to utilise the prenatal concentration proportional to their digit ratio. As a result the validity of the 2D: 4D digit ratio as a physiological marker of prenatal testosterone and oestrogen remains and consequently no alterations need to be made to the design of this current investigation.

A recent research development

Manning, Bundred, Newton and Flanagan (2003a, p.1) now propose that, even though 2D: 4D is sexually dimorphic, "there is no direct evidence for an effect of prenatal sex steroids on digit ratio". They state that previous evidence linking 2D: 4D with prenatal sex steroids is based on associations between digit ratio and other physiological characteristics, which are themselves dependent on sex steroids, such as waist: hip ratio. "Because of the indirect nature of these relationships, we cannot be certain that the 2D: 4D of the subjects is directly linked with their prenatal exposure to testosterone" (Manning et al, 2003a, p.2). Their study proposes two variables, which are independent of one another, to be important for the degree of foetal masculinisation: firstly the amount of prenatal testosterone and secondly the structure of the X-linked androgen receptor (AR) molecule. There is great diversity in human and non-human primates in regards to variations in the number of nucleotide (CAG) repeats of AR alleles (in the N-terminal domain) with the number of CAG repeats found to be inversely proportional to testosterone sensitivity (Chamberlain, Driver & Meisfeld, 1994; Kazemi-Esfarjani, Trifiro, and Pinski, 1995). Manning et al's (2003a) study confirmed this, finding the right-hand 2D: 4D of 50 Caucasian men to be positively correlated with the number of CAG repeats of the AR. CAG numbers, however, were only found to account for 0.09

percent of the variability in the male participants' right hand 2D: 4D. This finding of modest explained variance was apparently not unexpected, as there are four major types of population variance to be considered in relation to varying 2D: 4D including: prenatal testosterone, sensitivity to testosterone, prenatal oestrogen and sensitivity to oestrogen. Links between AR and 2D: 4D have also found to be related to ethnicity, fertility and behaviour (Manning et al, 2003a).

Even though the afore mentioned study aims to call into question the strength of the relationship between prenatal androgens and 2D: 4D by accentuating the importance of the role of the androgen receptor gene, it later goes on to state that it is only prenatal androgens and androgen receptor genes which have a major influence upon 2D: 4D ratio. With only 0.09 percent of the variance in their male participants' right hand 2D: 4D ratio found to be attributed to CAG numbers and without making any alternative explanation, the majority influence on variance in 2D: 4D still appeared to be caused by prenatal testosterone and oestrogen! As a result the theoretical basis of this current investigation seems to be unaffected by this recent publication.

Alternative physiological indicators of prenatal androgens

Other physiological measures are also considered to be valid markers of prenatal androgen concentrations. Jamison, Meier and Campbell (1993) proposed that prenatal testosterone modifies the development of the epidermal ridges of the digits. Ridge numbers and ridge depth are positively correlated with prenatal testosterone concentrations. This is further confirmed by evidence that males have a higher digit ridge count than females (Penrose, 1967).

2D: 3D ratio as well as 2D: 4D ratio has been found to be sexually dimorphic with lower values in males (Phelps 1952). Therefore it is likely that most tissues in the third as well as the fourth digit are sensitive to androgens. The sexual dimorphism of 2D: 3D is however less than that of 2D: 4D, suggesting that the third digit is less sensitive to prenatal testosterone than the fourth. Consequently 2D: 4D ratio will be favoured by this current investigation as a more sensitive physiological measure of prenatal androgens.

The simple measure of the fourth digit subtracting the number one (4D –1), has been shown (Manning, 2002b) to be a powerful correlate of fetal-androgenisation in populations with low means for 2D: 4D. The fact that reliable and valid associations can be observed with regard to only the fourth digit (which represents testosterone), without taking into account second digit measure (which represents oestrogen) suggests that testosterone has a more dominating influence than oestrogen and consequently should be the major focus of associated research. Previous research appears to confirm that of these two major sex hormones, testosterone is the prime influence on low or high 2D: 4D digit ratio regardless of oestrogen concentrations, with many of Manning's papers omitting completely any mention of prenatal oestrogen in relation to 2D: 4D digit ratio.

Another alternative physiological indicator of prenatal androgens is waist: hip ratio (WHR). WHR is a sexually dimorphic trait, which becomes more obvious after puberty and it is known to be a positive correlate of prenatal testosterone. There is considerable variation of WHR particularly among women, with high WHR women having high prenatal testosterone and low prenatal oestrogen, while low WHR women are found to have low prenatal testosterone and high prenatal oestrogen levels (Evans, Hoffmann, Kalkhoff and Kissebah, 1983). Mothers' WHR has also been found to be negatively associated with the digit ratio of their children (Manning, Trivers, Thornhill & Singh, 2000).

Digit ratio and other hormones

2D: 4D digit ratio has been associated with hormones other than testosterone and oestrogen. Manning et al (1998) found 2D: 4D in right hands of male and female participants to be positively correlated with lueteinizing hormone (LH), after controlling for sex, age, height and weight. As a result females are generally found to have higher LH concentrations then males. LH production in males is controlled by negative feedback with testosterone (Bell, Emslie-Smith and Paterson, 1980). Therefore low 2D: 4D in men is associated with both high testosterone and low LH. In females LH is controlled by both negative and positive feedback with oestrogen depending on their relative position within the menstrual cycle.

Is 2D: 4D fixed/stable?

The foetus begins to produce testosterone at about week eight of development, which is maximally produced in week thirteen (Migeon and Wisniewski 1998). Relative finger length and thus digit ratio appears to be fixed by week fourteen in-utero (Garn, Burdi, Babler and Stinson, 1975). From then on, digit ratio is considered to be stable throughout life. It is perhaps worth noting that, because 2D: 4D is the relative ratio between two finger lengths, large growth spurts (i.e. from foetus to full grown adult) will not change the ratio as long as both fingers grow at identical rates as they are known to do.

Manning et al (1998) investigated the 2D: 4D digit ratio of both hands, taken from eight hundred male and female participants varying in age from two to twenty-five. They concluded there to be no significant changes in 2D: 4D ratio with age. This study can be criticised, however, as mean trends over a population cross-section are a poor approximation to a longitudinal design. These findings were, however replicated by Manning et al (2000a) using a far more suitable longitudinal and cross-cultural design. They found no significant changes in 2D: 4D ratio across puberty, the most extreme of the testosterone-related physical developmental stages.

It would be wise, before making any concrete conclusions regarding the stability of digit ratio, to investigate a large population base using repeated longitudinal measures from the earliest possible age. It would be useful to take male and female participants from a variety of ethnic origins and measure their 2D: 4D repeatedly from the earliest possible opportunity together with their blood and saliva (free) testosterone and oestrogen measures. It would then be possible to discover if digit ratio is indeed fixed from week fourteen in *utero* throughout life. Also if there were changes in ratios it could be established if they were related to free sex hormone concentrations, thus showing whether hormones have any influences on digit length postnataly, as they are known to have on other physiological characteristics (i.e. muscle growth and development of secondary sexual characteristics at puberty). Such a study would probably prove too costly and time consuming to be considered.

Is there a difference between which hand is measured?

Manning (2002b) states that the concentrations of various hormones in men and women have been found to be more strongly represented in the right hand then in the left hand. There does appear to be a noticeable difference between the 2D: 4D ratio of the left hand compared to the right. Tanner (1990) found that sexually dimorphic traits, particularly 2D: 4D ratio, were expressed more prominently on the right side. Manning (2002 b) concludes that the relationships between left-hand 2D: 4D and testosterone-dependent traits tend to be much weaker. It may be that digit length on the right hand is more sensitive to early androgen exposure than those on the left, as postulated by Csatho et al (2002). This view is supported by Brown, Hines, Fane and Breedlove (2001), who investigated sufferers of congenital adrenal hyperplasia (CAH) a disorder characterised by extremely high concentrations of prenatal testosterone. Their investigations revealed participants with CAH to have significantly lower digit ratios in their right hands than in their left hands. Manning, Barley, Lewis-Jones, Walton, Trivers, Thornhill, Singh, Rhode, Bereckzei, Henzi, Soler and Sved (2000a) also support this claim after investigating international populations from Poland, Spain, England, Hungary, Germany and Jamaica, finding lower ratios in men's right hands and lower ratios on women's left side. Marshal (2000) found heritability coefficients to be higher for 'the first digit minus the number one' between fathers (but not mothers) and offspring on the right hand.

Jamison et al (1993) and Holt (1968) present further evidence for the occurrence of the lateralisation of hands in the expression of testosterone/oestrogen concentrations. Their data, taken from the ventral surface of the hands, showed lower ridge counts and pattern intensity in right hand compared to left where testosterone is low, as in women (Kimura and Carson, 1995) and higher ridge counts and pattern intensity in the right hand compared to the left hand when testosterone concentrations are high, as in males (Penrose 1967). These 'dermatoglyphic' patterns are fixed before the nineteenth week in-utero, therefore suggesting relationships between prenatal androgens and the formation of the epidermis and dermis upon the hands.

Hormones other than testosterone and oestrogen that have been found to be correlated with digit ratio also show hand lateralisation. Concentrations of leutinising hormone and prolactin which are positively correlated with 2D: 4D digit ratio, are also expressed more strongly in the right hand (Manning, 2002b).

Although the research regarding the left/right hand digit ratio and sensitivity to androgens is not definitive, the bulk of previous research does indicate that the digit ratio of the right hand is a more sensitive marker of testosterone, while the digit ratio of the left hand is perhaps a more sensitive marker of oestrogen. As it has been established that prenatal testosterone is the dominant influencing hormone with regards to the correlations between digit ratio and other variables, this current investigation will take the 2D: 4D digit ratio from the right hand of all participants.

Is digit ratio inherited?

Offspring digit ratio is highly correlated with that of the mother. An explanation for this, is that maternal testosterone crosses the placenta and affects the differentiation of the ovaries and digits of the in-utero offspring. In a longitudinal study of mothers and their infants (Lutchmaya, Baron-Cohen, & Raggett, 2002), high concentrations of foetal testosterone were found in the amniotic fluid of low 2D: 4D pregnant mothers. The mothers and children attended a twenty-four month follow up, and flatbed scans of their hands were obtained. Both mothers and children were found to have significantly correlated 2D: 4D measurements.

Similar findings were reported in the 'Jamaican Symmetry Project' (Manning, Trivers, Thornhill and Singh, 2000), which looked at eighty-eight mother-child pairs. Significant positive correlations between the mean 2D: 4D ratios of mothers and their children were found, with stronger correlations found between mothers and sons than between mothers and daughters.

Jamaican women's WHRs (Waist-hip-ratio) were found to be correlated with the 2D: 4D of their sons and daughters (Manning, Trivers, Singh and Thornhill, 1999). As predicted, it was found that women with low WHRs had high 2D: 4D ratios, as did their children, while women with high WHRs had low 2D: 4D ratios as did their children. This study also reported that women with high WHR (and thus higher prenatal testosterone concentrations) have more sons and fewer daughters, acting as further evidence for the in-utero masculinization effect of prenatal testosterone upon the foetus. Regarding the two previously mentioned studies, it should be noted that Jamaican women have significantly higher mean prenatal testosterone (and hence lower digit ratios) than most Caucasian females and often significantly higher means than some Caucasian men also! As a result, such significant findings may not be true of other populations characterised by lower prenatal testosterone.

There appears to be far less research on the father-offspring heritability of digit ratio. However two studies, Marshal (2000) and Ramesh and Murty (1977), did include father-offspring (as well as mother-offspring) correlations in their investigations. Marshal (2000), whose participants were Caucasian Liverpudlians, found father-child pairs to actually show higher heritability than mother-child pairs regarding 2D: 4D digit ratio. His samples showed no evidence of assortative pairing for 2D: 4D. Ramesh and Murty (1977) investigated parent-offspring heritability within a hundred-and-ninety Indian families and concluded that heredity was a significant influencing factor regarding 2D: 4D ratio. They calculated a heritability estimate of forty to seventy percent from parent-offspring and full sibling correlations. It should be noted that in their same research, however, Ramesh and Murty found no evidence for sex differences in 2D: 4D.

What can 2D: 4D predict and why?

Geschwind and Galaburda (1985) proposed that high levels of foetal testosterone compromise the development of the left cerebral hemisphere of the brain while simultaneously facilitating the development of the right hemisphere of the brain. Consequently there are a number of associated traits which have been found be to significantly correlated with low 2D: 4D ratio, these include: better male visual spatial ability, as assessed by mental rotation and judgement of line tasks (Manning and Taylor, 2001), left hand preference in peg moving in children (Manning et al, 2000b), a higher occurrence of autism (Manning, Baron-Cohen, Wheelwright, & Sanders, 2001), greater representation in membership of a symphony orchestra compared to controls, with higher ranking musicians found to have lower ratios than low-ranking musicians (Slumming and Manning, 2000), a higher occurrence of congenital adrenal hyperplasia (Brown et al, 2001), increased reproductive success and frequency in males (Manning et al, 2000), superior mathematical ability (Kimura, 1996), increased incidence of male/female homosexuality (McFadden and Champlin, 2000; Robinson and Manning, 2000), lower socio-economic status of males, as measured by the 'Townsend Deprivation Score' (Manning, 2002b) and finally, low 2D: 4D digit ratio is negatively correlated with verbal fluency (Varley, 1995). This list is not exhaustive, but does demonstrate the diverse traits with which digit ratio is associated.

The validity of digit ratio as a physiological measure of prenatal testosterone is further supported by the fact that extremely similar findings have been reported in studies investigating traits in association with saliva and blood testosterone concentrations.

Participants' high free testosterone levels were positively correlated with left-handedness, visual spatial, mathematical and musical abilities (Benbow, 1998; Gotestam, 1990; Grimshaw, Sitarenios and Finegan, 1995; Kimura and Hampson, 1994). This strongly suggests that the influences of free testosterone are extremely similar if not identical to the influences of prenatal testosterone (as represented by 2D: 4D). There is a far more extensive body of research reporting correlations between free testosterone with other variables, in particular personality traits, whereas parallel research using 2D: 4D is sparse. Consequently, much of the evidence used in the formulation of predictions/hypotheses in this current investigation regarding correlations between 2D: 4D ratio and personality traits will be drawn from free testosterone-personality studies.

2D: 4D and health

2D: 4D appears to have strong positive associations with health and physical well-being, which may at least in part, be why it is associated with sports success and achievement. In a recent personal correspondence Manning stated "I personally think the association between 2D: 4D and success in sport is mainly the result of the correlation between 2D: 4D and cardiovascular efficiency in men" (personal email received: Nov, 12, 2003). Manning's assertion of the major role of cardiovascular efficiency, seems to selectively ignore and even contradict his previously published work regarding the importance of other digit ratio-associated variables in regards to sport success, such as mental rotation ability and assertiveness (Manning and Taylor, 2002; Manning, 2002a).

There is previous research to support associations between free-testosterone and cardiovascular health. Austin, Manning, McInroy and Mathhews (2002) found the formation of the cardiovascular system to indeed be sensitive to testosterone, while Rosano, (2000) found that testosterone actually maintains a healthy cardiovascular system and prevents related malfunctions, in particular myocardial ischemia in men with coronary heart disease (Rosano, Leonardo and Pagnotta, 1999). Men with coronary heart disease have been found to have lower testosterone than controls (English, Mandour, Steeds, Diver, Jones and Channer, 2000), as have heart attack survivors (Askut, Aksut, Kararemehmetoglu and Oram, 1986; Phillips, Pinkernell and Jing, 1994; Sewardson, Vylithingum, Jailal, Desai and Becker, 1990).

As research shows free-testosterone to be correlated with health and in particular cardiovascular health, similar correlations would be expected with regard to 2D: 4D. This has been found to be the case: Low 2D: 4D is associated with a reduced risk of premature myocardial infarction in men (Manning, 2002 b). Manning (2002a) states that elite athletes from any sport demanding high cardiovascular efficiency are likely to have low 2D: 4D. Lower 2D: 4D has also been linked to male fertility, being correlated with higher sperm counts in male participants' ejaculates, with men who produced no sperm or inactive sperm having high digit ratios in the right hand (Manning et al 1998).

Interestingly most of the previously mentioned research, showing higher testosterone/lower digit ratio to be correlated with positive health, was performed solely on male participants. Alternative research, however, suggests that high testosterone/low digit ratio may be detrimental to good health in women, at least in regard to fertility. In women, high testosterone is related to high WHR and an accompanying disruption in the homeostasis of the glucose-insulin balance, causing negative health and fertility implications such as increased miscarriage risk (Kissebah, Vydelingum, Murray, Evans, Hartz, Karlkhoff and Adam, 1982). Manning (2002b) reported pregnant women with low 2D: 4Ds to have less successful birth rates than those with high 2D: 4D ratios.

In males as well as females, testosterone has also been associated with breast, ovarian, prostate, lung and colon cancer as well as malaria, tuberculosis and susceptibility to infections by HIV (Manning, b, 2002). No unequivocal conclusions however can as yet be drawn, as direct research regarding these associations with prenatal testosterone or 2D: 4D has yet to be performed. Recent direct evidence is available regarding an association between low digit ratio and less severe skin ailments. Caucasian participants with low 2D: 4D were found to have a higher susceptibility to sunburn, athletes' foot and eczema (Manning, Bundred and Mather, 2003). The cause is suggested to be the influence of prenatal testosterone upon skin pigment.

2D: 4D and personality

There is a body of research relating androgens to personality (to be discussed later in introduction). There is far less research, however, with regard to correlations between 2D: 4D and personality traits. Some of the more prominent studies will be mentioned subsequently. Wilson (1983) found that women with low 2D: 4Ds are likely to rate themselves as more competitive and assertive than women with high ratios. The credibility of Wilson's study should perhaps be questioned, as it was a questionnaire in a British newspaper where female participants measured their own digit ratios, thus raising questions regarding reliability and validity of the measuring procedures. Csatho et al (2002) found that female participants with lower 2D: 4D ratios endorsed more masculine traits on a masculinity scale and less feminine traits on a femininity scale, while Neave, Laing, Fink and Manning (2003) found male 2D: 4D to be significantly negatively correlated with perceived dominance and masculinity.

Austin, Manning, McInroy, and Mathews (2002) found only weak correlations between digit ratio and personality. The same study however found no sex differences with regard to digit ratio, as well as incorporating a large number of general personality scales and thus inflating the possible occurrence of type one errors. The findings from this study should therefore be treated with caution. A recent study by Fink, Manning and Neave (2004) which only incorporated the 'big five' personality factors of: Extroversion, Neuroticism, Openness, Conscientiousness and Agreeableness, still however, only found there to be weak associations between digit ratio and these personality factors with stronger associations found among the female participants. In this study Neuroticism was found to be significantly correlated with right hand digit ratio.

Manning (2002b) states that evidence for a relationship between digit ratio and assertiveness and aggression is at present weak, suggesting that testosterone has only weak effects on these traits. This statement contradicts much previous research correlating testosterone with assertiveness (Archer, 1991). Boys and girls with congenital adrenal hyperplasia (associated with far higher concentrations of prenatal testosterone) were self-rated and observed to be more assertive than same-sex controls (Migeon and Wisniewski, 1998). Testosterone has also been strongly correlated with aggression (Tremblay, Schaal, Boulerice, Arseneault, Soussignan, Paquette and Laurent, 1998; Olweus, Mattsson, Schalling and Low, 1980). Indeed Manning himself found that the fourth digit (a marker of testosterone), independent of the second digit was positively associated with self-rated measures of physical aggression (after adjusting for height) in boys aged twelve to seventeen using the Olweus Multifaceted Aggression Inventory (Manning and Wood, unpublished). Manning also stated in another published article that: "It has been suggested that high levels of in-utero testosterone may affect behaviour leading to greater assertiveness... low 2D: 4D may be a marker for such behaviour." (Manning, 2002a, pp449).

Ethnic and Racial differences

It is well documented that black (Afro-Caribbean) participants have significantly higher circulating and prenatal testosterone than Caucasian participants (Ellis and Nyborg, 1992; Ross, Bernstein, Judd, Hanisch, Pike and Henderson, 1986). Between population differences in 2D: 4D have been found to be even larger than sex differences. Manning et al (2000a) collected data from nine native populations from different international regions. Large variations in mean 2D: 4D occurred between the populations. High 2D: 4D values were found for participants native to England, Spain and Poland, intermediate 2D: 4D values were found for participants from Hungary, Germany and India and low 2D: 4D values were found for participants from South Africa, Jamaica and Finland. Males did tend to have a lower 2D: 4D than females, but in comparison to the population differences, these sex differences were minimal. Many females from the low 2D: 4D populations had lower ratios than males from the high 2D: 4D populations.

Ethnic physiological differences are not unique to digit ratio, For example, although the supra-orbital ridge of the skull is more pronounced in men than women to the extent that it is used as a reliable method for sexing a skull, a Caucasian male's supra-orbital ridge is often exceeded in size by that of a black female's (Knight, 1991). This is true of limb length comparisons also (Knight, 1991). Far more international research needs to be performed if precise conclusions regarding actual worldwide patterns of prenatal testosterone and 2D: 4D are to be made.

Since there are significant within-Caucasian differences in concentrations of prenatal testosterone and digit ratio, the next logical question to ask concerns the causes of this diversity. Manning (2002b, pp37) addresses this in terms of physiological adaptations to environment:

> Testosterone, vitamin d, and melanin compete for the same precursor, cholesterol (Bell et al, 1980). In areas with low levels of sunlight the synthesis of vitamin D is reduced. It may then be adaptive to reduce melanin production and therefore increase the synthesis of vitamin D. Reducing the production could also lead to an increase in the production of testosterone.

Therefore it is suggested that living in areas of varying sunlight intensity will influence testosterone production and digit ratio with a "low digit ratio in people of northern latitudes" (Manning, 2002b pp37). However, if digit ratio is set by the thirteenth week in-utero, it is difficult to see how sunlight would then have any direct effect on a foetus in the womb, unless the environment influences the mother and this effect is then transferred to the foetus. The viability of how sun exposure to a pregnant woman can affect the prenatal testosterone of her child is questionable, but as this issue is not directly concerned with the current investigation, it will not be considered further.

Manning (2002b) further suggests that variations in disease immunity, mating systems and local dietary preferences, or perhaps a combination of all three may additionally explain this apparent geographical and ethnic variation in 2D: 4D and prenatal testosterone. Appropriate research would need to be performed in these specific areas before any conclusions can be made about the relative proportional influence of these variables.

Sport and what it represents anthropologically

Successful athletes from a number of different fields seem to have many characteristics in common: cardiovascular and muscular endurance, strength, speed, flexibility, eye-hand co-ordination, and good mental strategy. These are many of the same traits which would be beneficial in male-male conflict or fighting. Top sportsmen also gain the same benefits of status, as 'dominant males': respect, an abundance of resources and sexual opportunities. The nature of many sports resembles male conflict even more obviously. Contact sports (such as boxing, karate, judo and fencing) and field sports (such as football, rugby and hockey) are primarily based upon the concept of invasion and defence of resources or bodily integrity, where there is a great emphasis placed upon territoriality: attacking, defending, protecting and invading. After a match there is usually a clear winner and loser with the winning side climbing the league tables or proceeding to the next round of a competition and thus increasing its position within the relevant hierarchy. Males appear to be more successful in virtually all aspects of sport (Holt, 1989) resulting in the occurrence of same-sex leagues and competitions to ensure fairness.

Athletes play according to stringent rules and laws overseen by officials such as umpires or referees. Often behaviour gets 'out of control' due to intense rivalry, pressure to win and players' disregard for the rules. In many sports, the organised game can dissolve into chaos if adequate discipline is not maintained. Common to many male supporters is loyalty to their team, which is so extreme in many cases that they jeer at and fight with opposing teams' supporters. Constant police vigilance is needed at sports events in many countries to prevent criminal damage, assaults and in extreme cases murders.

2D: 4D as a predictor of actual sports performance

Judgement of sports performance can be highly subjective and influenced by personal preference and opinion. The best way therefore to evaluate if 2D: 4D is correlated with sports performance is to choose a sport where performance is easily measured in an objective manner. Running in athletics with its reliance on accurate times is one such discipline. Manning and Vella (unpublished) examined 2D: 4D and the running speed of seventy-one (800m and 1,500 metre) runners who regularly trained and competed. Performances were measured by taking the mean times of the athletes' last three races. As predicted, men with low 2D: 4Ds reported faster times than men with high 2D: 4Ds for the 800m and 1,500m events even when the possible influences of variables including weight, height, training frequency per week, blood pressure, pulse rate, and age were removed. Interestingly, of all the control variables, only age was found to be a significant predictor of performance and then only in 800m races where older participants recorded faster times (mean age 22.93+/- 2.03).

Manning (2002b) later confirmed the importance of 2D: 4D in predicting running performance, especially for pre-pubertal athletes whose current performances often do not correlate with their adult best performances due to variations in development rate. Manning (2002b, pp131) suggests "It is likely that the variation in 2D: 4D within groups of young runners can be used as a predictor of adult running performance, which can be used in addition to other predictors".

Another study (Manning, 2002a) investigating 2D: 4D correlations with actual sport performance reported that low 2D: 4D was associated with faster skiing speed on a timed down hill slalom run, even after the effects of sex, age and skiing experience were removed.

Digit ratio as a predictor of achievement rank in team sports

Another objective way of investigating the correlation between digit ratio and sports performance is by investigating digit ratio's correlation with achievement rank. Achievement rank can be considered as the level at which an athlete competes, such as county or international. Manning and Taylor (2001) tested a-hundred-and-twenty-eight male university sportsmen who participated at various levels of ability in football, martial arts, rugby, tennis or squash, swimming and hockey. All the participants were given a sports achievement rank questionnaire. The 2D: 4D of the participants' right hand was found to be a significant predictor of their sporting rank with low 2D: 4D associated with high rank. A multiple regression analysis showed the 2D: 4D of the right hand remained a significant predictor of sporting rank after the effects of age, experience and type of sport were removed.

Football is considered a quintessential example of a field sport, where participants need high levels of cardiovascular fitness, strength, speed, agility and visual-spatial ability to succeed at the highest level. Manning and Taylor (2001) performed an extremely elaborate study on the correlation between 2D: 4D and achievement rank in football players, incorporating large numbers of past and present international and professional players. The most prominent findings were: professional footballers had a lower mean 2D: 4Ds than controls, professional players in first team squads had lower 2D: 4Ds than reserves or youth team players and men who had played at international level had lower ratios than those who had not. There was also an indication that among international players, those with lower ratios had higher numbers of caps. Interestingly, despite the low proportion of black players in the sample, they had significantly much lower mean 2D: 4D digit ratios than the white players. As low digit ratio is associated with player rank, this may at least partly explain why in sports such as football and basketball there is a disproportionate representation of black players at the highest club level and may indicate a greater potential for sporting greatness in this population subgroup. Obviously this cannot be confirmed without further research.

Youth Screening and development programmes

It was previously mentioned that Manning (2002b) considered 2D: 4D as a possible predictor of running performance, particularly for pre-pubertal athletes. Because the previously mentioned studies have found such strong correlations between team sport rank and digit ratio, 2D: 4D should be considered in predicting potential in team sports success also. In team sports, often more so than in athletics, selecting pre-pubescent youths who are likely to become exceptional adult players has traditionally proven extremely costly and relatively fruitless. Digit ratio could be used as an effective tool for screening and identifying youths with exceptional potential who could be given access to intensive development programmes and excellence centres at the earliest possible age. This would increase the likelihood of young players meeting their sporting potential by nurturing them with the best recourses and facilities at the youngest possible age in a more reliable, efficient and cost effective manner. This sentiment is shared by Morris (2000, pp725), who in his review of research regarding talent identification in soccer concluded:

Competition for schoolboy international places in soccer are very strong. Despite this, few school boy internationals progress to places in the full international team. Early selection could facilitate coaching. I would stress that digit ratio must be used as an addition to the judgement of coaches. Low 2D: 4D ratio is unlikely to be a strong indicator of football ability in a randomly selected group of males. However, in a sample of young males who have not yet entered puberty and who show some football ability, it may provide as an additional discriminator that helps to predict ability.

The use of digit ratio for talent identification could have unwelcome implications if there is an over-reliance on its use for recruitment and employment termination, without regard for actual player merit and performance profile. Digit ratio as a predictive tool could also be abused for use in international 'player poaching' (the coaxing of players with financial incentives from poorer national clubs/teams by wealthier national clubs/teams). These two issues will be elaborated upon in the discussion of this current investigation.

Chapter 2: Personality and sport

Sport science research has focused considerable attention on efforts to delineate the mental and physical attributes of high performance athletes. (Davis and Mogk, 1994, pp1)

This next chapter is concerned with reviewing literature of personality research associated with sport participation and performance and testosterone and oestrogen concentrations, so as to develop the rationale for the choice of appropriate personality variables to be incorporated and tested in this current investigation. The main issues and problems associated with previous personality research within a sporting context will be identified (such as design flaws and classification discontinuity) so as to allow attempts to resolve these issues with regards to the design of the current study. Finally a literature review specific to the actual sports, with which the participants in this current study will be drawn from will be made, to allow the extent of variation between these sports of differing contact intensity to be ascertained.

Personality can be considered as dispositional determinants of habitual activities, which to some extent are stable and inherited (Myers, 1999). Personality is an integral contributing factor to sports achievement for those involved in professional/elite sport. "It is recognised that psychological factors often distinguish those successful at the highest standard from their less successful counterparts" (Morgan, 1980, p.2). Fifty years ago, the influence of personality was considered to be far less important for sports success provided that an athlete trained sufficiently (Heider, 1944). In subsequent decades of research however, personality has been considered to have far more of an important impact:

> Success in sport is probably partially associated with the presence of ideal personality characteristics that facilitate learning/training and competitive advantage.... Many traits interact to help produce conditions more or less favourable for the potential to attain expertise in specific sports. These have been difficult to specify as research results are not conclusive, this may be due to methodological problems, complex individual differences, or compensatory abilities." (Singer & Janelle, 1999, pp128-129).

Inconclusive research

Even though the relationship between personality and sport success is accepted as highly important, findings from previous research have been inconclusive. Cox (1998), who performed a literature review of the field concluded: "it is good to remember that the relationship between sport performance and personality is still far from crystal clear" (pp2). This conclusion is also shared by Vealy (1992) whose own review concluded that there is no distinguishable 'athletic personality'. The reasons for these inconclusive findings from previous research have been suggested to be largely due to "methodological weaknesses in previous research" (Eysenck, 1971, pp86). These weaknesses will be investigated in greater depth later in this chapter following a review of personality traits considered to be associated with sport performance.

State or Trait

Before continuing further, a brief summary will be now be presented regarding a critical topic in personality related psychological research: that of personality traits versus personality states.

A trait can be defined as a "lasting disposition towards certain types of behaviour" in comparison to a state, which can be described as "a momentary mood or reaction to specific situations" (Spielberger, 1971, pp266). The main distinction between the two is that a state is regarded as relatively temporary and a trait is regarded as relatively constant. There has been much academic disagreement regarding the relative influences of traits and states within personality. Traditionally personality researchers were mainly trait theorists such as Allport & Odbert (1936) and Eysenk (1967). Their position was seriously questioned by Mischel (1969) when he published a landmark book: "Continuity and Change in Personality", where he questioned the importance of trait variables saying that behaviour was characterised far more by situationally induced states. Although Mischel has been challenged by latter trait theorists such as Alker (1972), the current consensus is to accept the contribution of both states and traits together and to adopt a more holistic approach (Spielberger, 1983) particularly, within a sporting context.

It should not be assumed, however, that states and traits are that vastly dissimilar from one another. Correlations between states and traits are often in excess of 0.5, which when corrected for attenuation, suggests that about half of the variance of state measures can be predicted from trait measures (Eysenck, Nias and Cox, 1982). Various personality traits have been reported to account for twenty to forty five percent of the variance in sport performance (Morgan, 1980). Morgan concludes that trait theory should certainly not be abandoned, but neither should it be thought of as being an exact predictor of sports performance. Rather it should be thought of as being theoretically useful in predicting behaviour if used in addition to other predictive measures.

Some state measures of moods may correlate even more highly than traits with athletic performances and sporting activity. Anxiety, in particular, has been found to be more negatively correlated with performance when state measures rather than when trait measures are taken. The same has been found true for feelings of energy, competitiveness, and other similar variables (Eysenck, Nias and Cox, 1982). Even if a state measure is not as good a predictor as a trait measure for a particular outcome, the additional information given from a state measure can be most useful. To know an athlete's current psychological state is very important to fully understand their determinants of success in sport.

Review of research on specific personality variables within a sports context

Extroversion

Eysenck (1975) describes extroverts as being: outgoing, talkative, high on positive affect (feeling good) and in need of external stimulation, with introverts (extroversion reversed) representing the opposite to this, as the two traits are considered opposite poles of a continuum. Even though there is a lack of conclusive research regarding a relationship between personality traits and sports performance/achievement rank (as previously mentioned), the trait that most consistently shows a positive relationship with sports success is extroversion.

In later research, Eysenck (1979) suggests why extroverts are more likely to take up sports and excel in them. Their lower cortical arousal levels causes them to seek sensory stimulation through bodily activity (sensation seeking) as well as making them better able to tolerate the physical pain that is often associated with sport training and performance. Extroversion is also associated with increased assertiveness and competitiveness, which in turn are often found to be positively correlated with sporting excellence. We would accordingly expect sport participants to be more extroverted than non-participants and to find leading sport participants to be more extroverted than average participants. Warburton and Kane (1966) found above average extroversion in Olympic competitors in comparison to non-sport participants. Extroversion was also found to be consistently associated with sporting excellence across a wide range of different sporting domains in a literature review performed by Eysenk, Nias and Cox (1982).

Petrie (1978) argued that extroverts are '*reducers*' and introverts are '*augmenters*', in other words the former because of their low level of arousal, reduce the intensity of incoming stimulation (reduction) while the latter because of their high level of arousal, amplify incoming stimulation (augmentation). The degree of augmentation/reduction has been considered to be associated with ability to anticipate. Extroverts are thought to be better sports performers, at least partially, because of their ability to 'read the game' (Jones and Miles, 1978). Ability to anticipate is thought to be far superior in extroverts in comparison to introverts because of the reliance of introverts upon augmented feedback, which does not properly allow them to effectively anticipate changes in stimuli (Heldman, 1981).

Sociability, a central feature of the extroversion dimension of the Eysenck Personality Questionnaire, is a characteristic that does not seem to be entirely compatible with the long hours of repetitive and often solitary training that is required for success in many sports. This is particularly true of individual sports where isolation appears far more extreme. Some studies investigating associations between extroversion and excellence in sport have investigated the difference between team versus individual sports participation. As expected, Booth (1958) found extroversion to be more common in team than in individual sport participants and similarly Peterson, Weber and Lonsdale (1970) found introversion (interpreted as self-sufficiency) to be more apparent in individual than in team sport participants.

Sensation seeking

Sensation seeking is defined by Zuckerman (1979, p.1) as a trait characterised by "the need for varied, novel, and complex sensations and experiences and the willingness to take risks for the sake of such experiences". A high sensation-seeking individual is described as being orientated to bodily sensations, thrill seeking, is active, impulsive, antisocial or non-conformist and low on anxiety (Zuckerman & Links, 1968). There is an obvious connection between sensation seeking and extroversion as mentioned previously. "Both extroversion and sensation seeking have been theoretically related to the construct of an 'optimal level of stimulation'"(Eysenk & Zuckerman, 1978, p.483). Success in many sports, but particularly high-risk and contact sports, is associated with a degree of risk taking and sensation seeking and the ability to deal with potentially dangerous situations (McCutcheon, 1981). High risk/contact sport players have been found to score higher on sensation seeking than low risk/non-contact sport players (Fowler, von Knorring and Oreland, 1980; Zuckerman, 1983). A study comparing rugby players and marathon runners found rugby players to score higher on both the total Sensation Seeking Scale (SSS) and the Thrill and Adventure Seeking (TAS) subscale of the SSS (Potgieter and Bisschoff, 1990).

Impulsivity

A dictionary definition of impulsivity is: "acting carelessly or too hastily" (Collins Gem English Dictionary, 1992). Early research assumed impulsivity to be a contributing subscale of sensation seeking (Eysenck and Eysenck, 1977). Consequently the majority of research regarding impulsivity and sport has been undertaken in conjunction with sensation seeking (as mentioned below). More recent research has however seen it develop into its own different and distinct entity, with Buss and Plomin (1984) defining impulsivity in terms of decision time, inhibitory control and persistence. Schalling, Edman and Asperg (1983) confirmed that impulsivity and sensation seeking (monotony avoidance) are two very independent traits rather than one being subsumed by the other. This is confirmed by Zuckerman (1983c) who after performing a literature review on sensation seeking, concluded there to be clear differences between the traits of impulsiveness and sensation seeking.

A study by Stanford, Greve, Boudreaux, Mathias and Brumbelow (1996) clearly demonstrated a strong relationship between impulsiveness and high-risk behaviour in adolescents and young adults, warning that impulsive adolescents are at a considerably higher risk of personal injury because of their increased impulsiveness. McCutcheon (1981) found contact sport participation (such as rugby and American football) to be related to elevated impulsiveness and sensation seeking scores compared to non-contact sport participation and non-sport participation. These findings are further supported by Schroth (1995), who studied male and female university sports performers using Zuckerman's (1978) scale. He found athletes to have significantly higher impulsivity and sensation seeking scores than non-athletes overall, with rowers and soccer players having lower impulsivity scores than rugby and lacrosse players.

Arousal avoidance

Arousal avoidance is regarded as the polar opposite trait to sensation seeking and thus can be defined as: the need to avoid complex, novel and varied experiences and to avoid taking any risks, which lead to such experiences. As a result the previously mentioned research regarding sensation seeking is just as applicable to arousal avoidance. Arousal avoidance can be reliably measured using Murgatroyd, Rushton, Apter and Ray's (1978) Telic Dominance Scale (TDS). Cowles and Davis (unpublished) found a highly significant negative correlation between scores for arousal avoidance (from the TDS) and Zuckerman's (1974) Sensation Seeking Scale.

> Arousal avoidance, as measured by the TDS, seems to be an important element in S's [subject's] preference for and participation in safe and risk sports. When given a free choice, those S's [subjects] who listed a safe, as opposed to a risk sport, as their first choice scored significantly higher on the arousal avoidance subscale than those who listed a risk sport as their first choice. (Kerr & Svebak, 1989, p.799).

Kerr and Svebak (1989) also found that sports which they categorised as 'endurance' (involving sustained activity such as marathon running) or 'explosive' (short intense bursts of activity, such as football or rugby) were found to score differently on the TDS. Explosive sport participants scored lower on arousal avoidance and higher on non-planning compared to the endurance athletes.

Achievement-orientation

Achievement orientation can be defined as an individual's motivation to attain a high level of performance or a pre-planned goal/given task. Within a sporting context it is expected that persons with a higher need for achievement will not only prefer more competitive situations but they will also do more to succeed in them (i.e. play harder and train more). Sports achievement itself can be operationalised as a personal best achieved in athletics or in other sports or the number of titles and 'silverware' that have been won from competitions, leagues and tournaments. To allow for a more standard application within sport, achievement can be judged in terms of the level or rank at which an athlete has participated (such as county, district, national, international) which can be termed their 'athlete achievement rank'. This allows for valid comparisons between different sports.

Achievement orientation (motivation to succeed) is considered a prerequisite for good sports performance. Research has shown that career advancement is strongly influenced by individual differences in motivation to achieve, particularly among persons who work independently (McClelland, 1990). This is often the case in sport, where results are, to a great extent, attributable to the athletes' motivation to train and to perform excellently in competition. Halvari & Thomassen (1997) found strong evidence across a variety of sporting domains that athletes with a high motivation to succeed, perform better than athletes with a high motivation to avoid failure. "...Motivation, commitment and hard work lead to exceptional success" (Singer & Janelle, 1999, pp121).

Elite athletes (professional, or international) report significantly higher achievement motivation in comparison to non-elite groups (Davis and Mogk, 1994), with female athletes scoring higher than male athletes overall (Vanek and Cratty, 1970). A possible explanation for this sex difference is that, for women to reach the same standard as men in a given sports domain, they will have to be far more motivated to compensate for the lesser value, resources and funds associated with women's sport. Within the general population, however Mehrabian & Banks (1978) found males to score higher than females on 'achieving tendency' on their 'Measures of Achieving Tendency Scale'.

Nias (1979), using the 'Edwards Personal Preference schedule', found that athletes scored above average on their need for achievement and below average on deference compared to non-athletes. Similar results were obtained by Balazs and Nickerson (1976) who studied twenty-four female athletes in the US Olympic team, whose highest scores were for 'achievement' and 'autonomy'.

Assertiveness

Assertiveness has been defined by Fiske (1971, p.2) as: "to insist upon/put oneself forward forcefully". Assertiveness is strongly correlated with extroversion and as mentioned previously is associated with sporting excellence (Eysenck, 1979). It might be hypothesised that assertiveness is a trait especially required by a team player in order to draw the attention of selectors to his performance, at least during the early stages of his career. It is certainly considered a desirable trait among competitive team sports, in terms of important decision-making and responsibility taking (Eysenck, Nias and Cox, 1982). It has been suggested that too many assertive players in a team could be detrimental to performance, with sports commentators often noting that 'there are too many Chiefs and not enough Indians'. However heterogeneity of personality within a group has often been shown to be associated with better performance by that group (Hoffman, 1959), therefore it is likely that the more assertive a sports team, the more likely they are to perform better.

Dominance

Dominance is defined by LeUnes and Nation (1989, p.2) as: "an apparent intent to achieve or maintain high status, which is to obtain power, influence or valued prerogative". Dominance, therefore, shares many similarities with both 'achievement orientation' and 'assertiveness'. Within a sports context if an athlete or team can dominate their opponent/s, this will have positive implications for beating them in competition. Fletcher and Dowell (1971) reported that high school athletes score higher on measures of dominance and aggression compared with non-athletes, while Eysenk, Nias and Cox (1982) reported international athletes to be more dominant than non-international athletes.

Aggression

Aggression is defined by LeUnes and Nation (1989, p1) as: "An act committed with intent to harm". Although there is much sport related research regarding aggression, little will be mentioned in this current study, due to its questionable validity. This is primarily due to definitional ambiguity or misinterpretation of aggression. In many studies, aggression is measured by the number of tackles, steals, blocks and turnovers made in a game, in which intent to harm is incidental and is far more likely to represent effort, motivation or assertiveness.

Mazur and Booth (1998) conclude their literature review by noting that dominance and aggression are inextricably linked and that dominance (or high status) cannot be achieved if aggressive behaviour is never an option. They assert, however, that dominating actions are much more relevant in a sporting context than aggressive actions. Widmeyer and Birch (1979) reported that sports teams that win contests are more aggressive at the start of the contest (thought to be associated with attempts to assert their dominance), while losing teams are more aggressive near the end of competitions (perhaps associated with their frustration or desperation).

Anxiety

Anxiety is defined as a "stressful state resulting from the anticipation of danger" (Hayes & Stratton, 2003, p.19). Anxiety is considered to have a cognitive component (particularly in narrowing attention), a physiological component (in terms of 'fight or flight response') and a subjective experience of discomfort. The subjective element of anxiety will be elaborated further under the trait category of emotional stability.

Anxiety has been found to impair performance across a wide variety of sports domains (Burton, 1971; Hammock and Prince, 1954). This is thought to be due, at least in part to cognitive effects. Cognitive anxiety has been shown to impede the budgeting of energy over performance periods for both endurance and 'ball game' athletes as well as reducing reaction times, thus reducing athletes' potential for success (Eysenck, Nias and Cox, 1982). Cognitive anxiety, characterised by states such as worry and ruminations about failure, has also been shown to have debilitating effects on performances that have to simultaneously fulfil multiple criterion, such as speed as well as accuracy (Kuhl, 1994). There is a tendency for athletes, particularly outstanding ones, to score low on neuroticism and to suffer less from anxiety than non-sportsmen. Male elite athletes were found to have the lowest neuroticism scores when compared to sub-elite male athletes, female athletes and male and female controls (Davis and Mogk, 94; Silva, Shultz, Haslam, Martin and Murray, 1985).

Another explanation for the negative relationship between sport performance and anxiety/neuroticism lies in the '*drive stimulus*' qualities of anxiety, which distract athletes from their appointed task and relevant cues in competition, to the detriment of their performance. The trend from previous research findings seems definitely towards lower anxiety being correlated with better sport performance, particularly among outstanding athletes.

Emotional stability

Emotional stability can be described as a person's degree of firmness or consistence in regards the absence of neurotic and anxious tendencies. Cattell (1965) included emotional stability as one of the personality dimensions in his '16 Personality Factor' questionnaire (16PF). He defines the characteristics of low emotional stability as 'reactive, emotionally changeable, affected by feelings, emotionally less stable and easily upset' and high emotional stability as 'adaptive, mature, faces reality, calm'.

Emotional stability (low neuroticism/low emotionality) is correlated strongly with self-confidence, which in turn has been found to be associated with higher athletic performance among male and female athletes and also for athletes in comparison to non-athletes (Davis, 1992; Taylor, 1987; Williams, 1980).

An emotionally unstable athlete, even with good ability, would struggle in team and coaching situations because of any number of associated phenomena including: fearfulness of other players and the coach, social withdrawal, depression bouts, indecision, lack of self confidence (especially in response to defeat), over-sensitivity to criticism and poor interpersonal and interpretational skills. As would be expected then, after a literature review, Cattell, Eber and Tatsuoka (1982) concluded that sports participants suffer from lower levels of anxiety than non-sports participants, while college athletes scored significantly lower on the total mood disturbance and depression factors than non-college athletes (LeUnes and Nation, 1982). In sports associated with timely reactive events, emotional and temperamental control was also related to effective distributed or focussed attention and the ability to make good decisions and hence to improve performance (Janelle, Singer & Williams, 1999).

Physique and personality in sport

In the 1940s, Sheldon (1940, 1942), basing his research on previous work done by Kretschmer (1936,) believed strongly that there was a correlation between body build and personality type. He categorised humans into one of four body type categories: mesomorph (muscular), ectomorph (thin), endomorph (fat) and normal. Sheldon's research revealed strong correlations between mesomorphic build and extroversion and between ectomorphic build and introversion. Although Sheldon's studies involved impressive sample sizes and found very high correlations, his research has been strongly criticised in regards to the possible influences of 'self fulfilling prophesies' and particularly 'experimenter bias', as it was the author himself who both categorised the physique of the participants and rated their temperament

There is however more valid recent research to support some of Sheldon's initial findings. Males who were categorised as mesomorphs were significantly more likely to describe themselves as assertive and dominant, characteristics known to be highly correlated with extroversion (Eiben, 1972; Montermayor, 1978). More recent research has also found a correlation between introversion and ectomorphic physiques (Washburn, 1962). The overwhelming majority of team sports participants (who would be categorised as muscular and therefore mesomorphs) would also be considered to be extroverted (Booth, 1958; Peterson, 1976). This proposition is also supported by the fact that endurance athletes (who would be categorised as ectomorphs) are also rated as more introverted on personality scales (Eysenck, Nias and Cox, 1982).

Research on associations between body shape and personality has massively declined over the last few decades, especially within a sporting context. Even though body shape is regarded as genetically predisposed to a large degree, scepticism will still naturally occur when one measurement (body shape), which is unstable in nature and can be significantly altered through training or injury (particularly in athletes) can have a major influence on another measure which is considered to be stable and enduring (personality).

Eysenck's (1967) review of the biological basis of personality, strongly supports a genetic contribution to sporting ability. He also emphasises the fact that both body build and personality have a strong genetic determinant. He estimates that the influence of genetic factors on competence in many different sporting activities accounts for between seventy and ninety percent of the total variance. This finding does not suggest that training cannot help people to improve their performance, but it does suggest that selection for sport in general and for specific types of sport in particular, should take account of both personality and physique.

Issues regarding personality and sport research

Inventories used

Much of the previous research regarding associations between personality traits and sports performance have used well established general personality inventories such as the Eysenck Personality Questionnaire (EPQ) (Eysenck and Eysenck, 1975) and the 16 Personality Factor Questionnaire (16PF) (Cattell, 1965). However the approach adopted by much of this previous research incorporating these questionnaires has been strongly criticised for having weak conceptual foundations and methods (Cox, 1998; Morris, 1995; Schurr, Ashley and Joy, 1997).

Kroll and Petersen (1965a), after investigating collegiate football team members in comparison to non-sport playing college students with the Cattell 16PF, commented on the relative insignificance of isolating findings for a single subscale from a general questionnaire and also the considerable increase in type one errors associated with doing so. Eysenck, Nias and Cox (1982) also mention this issue: "While multivariate analyses can be informative, they do suffer from the obvious fact that such analyses capitalise on chance errors, and when the number of variables is large, and the number of subjects small, as is usually the case, these errors are accumulative and become quite large" (p.15). Most researchers who use multivariate analysis are aware of the increased likelihood of type one errors, but rarely check the generality of their findings by comparing them with findings from samples. This being the case, care should be taken when drawing conclusions from multivariate studies, with a profile analyses only being accepted after it has been crosschecked with other samples. A simple but regularly ignored suggestion to reduce the likelihood of type one errors is to use much larger participant numbers.

One of the most commonly used personality inventories in the sports domain, Cattell's 16PF (1965) has received much criticism, particularly regarding the validity of its individual items (Greif, 1970; Howarth and Browne, 1971; Timm, 1968). A common finding is that items originally found by Cattell to load on one factor often have much higher loadings on other factors. There is also little evidence for item heterogeneity for many of the factors (Howarth, 1976). "... When trained psychologists were asked to match the items constituting the various factors with the trait names given them by Cattell, they failed to do so" (Eysenck, Nias and Cox, 1982, p.4).

There are numerous criticisms of many of the most commonly used personality inventories. Cattel's 16PF was highlighted to underline the importance of the reliability and validity of an inventory and the possible problems associated with even well-established personality inventories.

Common design flaws

The general research strategy for much previous research on sports and personality, presumably based upon minimising effort, is to take an opportunity sample of ill-defined athletes (often chosen at random or on the basis of convenience), administer a general personality inventory (with little justification for its choice) and then see which variables significantly discriminate between sports and between standards of play by comparing mean values with standardized group norms (even though they differ in age, social status and other ways from sporting groups studied). This is clearly not the way to achieve scientifically valuable results and almost guarantees the results will be difficult to replicate, and of little importance.

More recent research in this field has shown improvements in the design of investigations, particularly in the increased use of select psychological variables that are specifically associated with sports performance. However common flaws are still apparent in terms of small sample sizes and the use of opportunity samples with no theoretical justification. If results are averaged over heterogeneous groups, important information may be lost. Unfortunately most studies have done precisely that, possibly because the samples involved were too small to disaggregate findings into more specific categories. By concentrating not on general groupings with extreme heterogeneity of traits, but rather on more specific groups within fields and areas, there is far more potential for fruitful findings to be obtained even with relatively small participant numbers due to this reduced generality and increased specificity.

Earlier research has also often failed to derive or state hypotheses, made little or no attempt to explain their findings or to develop theory. "Simply reporting similarities or variations in data is meaningless without a theoretical context from which to interpret the results" (O'Sullivan, Zuckerman and Kraft, 1998, p.119). Clearly interpreting data in the absence of hypothesis is bound to lead to post-hoc and local explanations (Eysenck, 1982).

Classification problems

More stringent and appropriate classification systems need to be introduced into this field of sports psychology to improve the power of statistical tests, by reducing within-group error variance and thus allowing more valid comparisons across studies. Many earlier studies have failed to distinguish participant sex, between team and individual sports and between levels of competition, despite the fact that much research suggests, somewhat obviously, that successful athletes from these different categories differ with respect to their psychological characteristics (Rowland, Franken and Harrison, 1986; Zuckerman, 1983).

The need for differentiation to be made in research between team and individual sports with regards to personality can be illustrated by hypothetically comparing ice hockey players with long distance runners. These sports are of such extremely different natures that competitors are likely to share little in terms of common personality traits. Many variables that contribute to success in individual sports events are different from those relevant to team sports. Team sports require interactive skill and adjustments to the context and skills of other players. Much also depends on the type and quality of opponents. In individual sports, such as golf, archery and diving, performance is exhibited in a relatively isolated condition. Any generalised conclusion about factors contributing to sport expertise is therefore misleading if the specific nature of the sport is not taken into consideration.

Comparisons within sports

Over-generalisation, therefore, appears to be an issue. Even making generalisations regarding personality of participants from the same sport may mask the possibly significant variation in some personality traits within those sports as a function of differing positional requirements. For example, not all footballers may share the same personality profile; goalkeepers may differ significantly from strikers, or full backs from midfield players. Minimal differences in past research might have been much larger had finer, less generalised distinctions within sports been examined (this field is discussed further in the discussion as a suggestion for further research).

Level of Participation

An important impediment to finding consistent and significant relationships between personality and athletic performance can be attributed to experimenters too-liberal classification of individuals as ‘athletes’, combined with a lack of a strict screening for those classified as ‘non-athletes’. Definitions of athletes have varied from members of the highest level in their country (Geron, Furst and Rotstein, 1986) to simply those active in university sports (Thakur & Thakur, 1980). The diversity of classification is equally bad when it comes to ‘elite’ or ‘high level performers’. Some researchers identify members of a county or state team/squad; some, a national team (Highlen and Bennet 1983) and still others include only current Olympic competitors (Balazs, 1980) to represent the elite. The usual criterion of non-athlete is non-membership of a school, college or university sports team, often without any additional screening for sport participation outside of the educational institution, such as playing for a village or town football team or undertaking a self-styled exercise programme like going to a gym, aerobics or running.

Many current personality researchers in sport still make very little if any distinction between participants of 'contact' and 'non-contact' sports. This variable is extremely important in regards to the personality types that are attracted to and excel in these different natured sports (O'Sullivan et al, 1998). There is a body of research demonstrating significant differences between contact and non-contact sports participants with regards to sensation seeking (Zuckerman, 1983, 1994) and dominance, arousal avoidance and non-planning (Kerr and Svebak, 1989). Failure to attend to this important distinction by classifying athletes from different sporting domains as belonging to a single homogeneous category is likely to obscure important differences between them.

Sex differences and sex hormones

Remarkably, many studies have also made no distinction with regard to the sex of participants in sports personality research. This still occurs despite a number of marked sex differences with regards to some major sports success-related personality traits. Among other traits, females have been found to score higher than males on scales of neuroticism and depression (Hawkins et al, 1989; Sowa & Lustman, 1984) as well as having a higher incidence of clinical depression (Brems, 1995). Males have consistently been found to score higher than females on psychotocism (Eysenck and Eysenck, 1976), aggression scales (Harris, Rushton, Hampson and Jackson, 1996), sensation seeking (Zuckerman, 1994) and 'achieving tendency' (Mehrabian and Banks, 1978). This list is far from exhaustive, but merely highlights the pervasiveness of sex difference in sports success-related personality traits. There is also evidence in the literature that women are more successful and better adjusted to sport achievement if their personalities more closely resembles that of men (Butt and Shroeder, 1980; Popma, 1980).

There is significant evidence indicating that the sex difference of some personality traits is associated with sex-specific differences in sex hormones concentrations. Testosterone is known as a primary androgen (a class of steroid hormone) considered the most potent hormonal determinant of physical and behavioural masculinization. It has long been implicated in the stimulation of sexual behaviour, as well as in the activation of dominance and aggressive behaviours in male primates including humans (Archer, 1991; Brain, 1983; Reiss and Roth, 1993).

Testosterone has been considered, particularly by the media, to have a predominant influence upon aggression. Higher testosterone has been positively associated with hostility and aggressive behaviour in males (Bergman & Brismar, 1994) as well as in females (Harris, et al 1996). Olweus, Mattsson, Schalling and Low (1988) found positive correlations between testosterone in adolescent males and acts of verbal and physical aggression and lack of frustration tolerance.

These findings, however, are far from definitive. Constantino, Gross, Saenger, Chandler, Nandi and Earls (1993), Eccles, Miller and Tucker (1988) and Archer, Birring and Wu (1998) among others have found no consistent association between high testosterone concentrations in saliva or serum and high levels of concurrent irritability and aggression. Udry (1990), in a three-year longitudinal study of male-undergraduates, similarly found no relationship between testosterone and psychometric measures of aggression. Further contradictory evidence comes from clinical syndromes, such as Klinefelters, where patients with very low testosterone levels are still found to behave in highly aggressive ways. (Johnson, Myhre & Ruvalcaba, 1970).

If testosterone is not consistently associated with aggression, could it be that it is associated with a similar trait, which, in turn, ***is*** associated with aggression? Mazur and Booth (1998), who concluded that testosterone was not related in any consistent way to aggression on standard personality tests, proposed that testosterone is related to dominance and associated traits that carry no intention of physical harm. There does appear to be appropriate evidence to support this suggestion. Spence, Helmreich & Stapp (1974), found men with higher testosterone to score higher on attributes of dominance and competitiveness and lower on sympathy and compassion. Zuckerman (1994) reported that high testosterone is found in assertive people, while Archer (1991) said: "higher or rising testosterone encourages dominant behaviour intended to achieve or maintain high status" (p.1).

Testosterone and personality traits

Positive correlations have also been found between free-testosterone levels and sensation seeking and engagement in dangerous activities for both males and females (Gerra, Avanzini, Zaimovic, Sartori, Bocchi, Timpano, Zambelli, Delsignore, Gardini, Talarico and Brambilla, 1999; Zuckerman, 1994,). Diatzman and Zuckerman (1980) found by administering a disinhibition subscale that low disinhibitors had average testosterone levels for their age, while high disinhibitors had unusually high levels of the hormone. In their studies, testosterone was also positively correlated with dominance and socialiability and negatively with self-control. Zuckerman (1994) found testosterone to be positively correlated with extroversion, thus supporting the findings of Diatzman and Zuckerman (1980) who found testosterone to be negatively correlated with introversion. Negative associations between testosterone levels and neuroticism have also been found to occur in males (Dabbs, Hopper & Jurkovic, 1990), while Diatzman and Zuckerman (1980) again found testosterone to be universally negatively correlated with depression. Dabs (2000) concluded that individuals with low free testosterone tended to be less focussed, more reticent, slower moving and overall less confident. This previous research indicates that testosterone appears to be positively associated with many traits regarded as beneficial for sports success and negatively correlated with many traits regarded as detrimental to sport success.

Within sport comparisons

A common research problem concerns the theoretical implications of group comparisons. Previous research has often compared elite sports players with members of the general population and then implied that the differences in personality scores obtained are indicative of sport success. This conclusion however, cannot validly be made unless the elite group is compared to a non-elite group from the same sport. Only if differences are apparent between the non-elite and the elite group can we conclude that these differences are associated with success within sport rather than simply participation in sport.

Bushan and Agarwal (1978) found significant differences when they gave personality inventories (16PF) to ten international table tennis and badminton players and compared their scores with those of ten low achievers in the same sports. The international players scored significantly higher on extroversion, dominance and surgence.

Other traits frequently encountered to be higher in the personality profiles of high-level competitors in comparison to lower level competitors, are: self-control (Bird, 1970), conscientiousness (Peterson et al, 1970) and intelligence (Ogilivie, 1970). Results unfortunately are not always easy to interpret because some studies do not clearly report what criteria were used to identify high levels of sports ability and, in some studies, comparisons are made between levels of competence within a group of players of fairly homogeneous ability (Singer, 1969).

Does sports participation change personality?

It is important to establish whether sports participation can change an athlete's personality, as this would have fundamental implications regarding the 'cause or effect' interpretation of research. It may be that, through long-term participation within a sport, aspects of an individual's personality adapt to increase their chances of success or alter due to the direct influence of participation. There is a body of research concerned with the influences of exercise/fitness programmes upon personality, which can be briefly summarised. After observing the personalities of volunteers who completed fitness programmes, Folkins and Sime (1981, p.375) report: "It appears that there is no evidence to support the claim that global changes on personality tests follow from fitness training" (pp375). Layman (1974), however, found fitness training to improve participants' self-concept, while Heaps (1978) argued that a person's own information about their fitness and its expected effects may influence their self concept, and thus may indeed play an important part in altering their personality. Folkins (1976) studied college students and found that twenty-one female students who completed a semester-long jogging course showed a significant improvement in anxiety, depression, self-confidence, adjustment and sleep. Even though his results were not found to be significant for male participants, he later replicated these findings with male cardiac disease patients put on a twelve-week exercise course (Folkins, 1976). The main issue regarding much of the research on introduced fitness programmes is that the majority of participants were self-selected volunteers, thereby limiting generalisation of the findings. There is also a large gap between the nature and demands of a fitness programme compared to participating in a sport.

Although there has been much debate in regards to the psychological effect of intensive sports training and competition (particularly in adolescents), there is still relatively little research in this area. Over a single season, Johnson (1966) found there to be an increase in players' ascendance and sociability, using the 'Guilford Zimmerman Temperament Survey' in a schoolboy American football team. Olgilivie (1970) studied elite youth swimmers, comparing ten year olds to fourteen year olds in a cross-sectional design and concluded that there was an increase in extroversion with age. The older swimmers also scored higher on self-assertion, independence and aggression. A far more useful design would be one that incorporates a control group for comparison and a longitudinal design for validity. This was done by Tattersfield (1975), who investigated a-hundred and-six competitive male swimmers aged eleven to fourteen from the north east of England matched with a-hundred-and-six boys not involved in competitive sport. An increase in extroversion and a decrease in anxiety were observed over a two-year period for the competitive sport participants independent of age.

With regard to the opposite direction of influence, there is a growing specialised field of sports psychology concerned with the modification of athletes' personalities to improve sports performance. Athletes often seek the aid of sports psychologists' modification techniques in such areas as: goal setting (to combat poor motivation), relaxation and visualisation techniques (to combat over-arousal and anxiety) and positive reinforcement and attribution theory (to improve self efficacy). These techniques have become widely used across many athletic domains, with reports of the success of trait/state adaptation and resultant increased player achievement (Brengelmann, 1981). More objective research evidence is needed in this field as many of the reports of the benefits of sports psychology treatments are personal accounts made by athletes and thus appear somewhat subjective.

To conclude, evidence exists to indicate that personality can be influenced by the introduction of a fitness programme, participation in competitive sport and the administering of a sport psychologist's programme. However, research in this area is sparse and many studies have far from ideal designs. As a result few definitive conclusions can be drawn apart from an indication that extensive sport participation may increase extroversion and associated traits.

Different personality traits for different sports

There are so many different competitively played sports, that even among team and field sports, the variation in terms of their characteristics and nature is huge. Such variation includes the extent to which fine or gross motor skills are required, the amount of strategy that is used and the amount of player interaction and contact intensity that occurs. Logic then suggests that different personality types may well be better suited to, and therefore more successful at, different types of sport.

Football (soccer)

Football is the most popular sport in the world, both in terms of playing and spectating. Football is a field-sport, which involves a moderate amount of physical contact between opposition players in regular competition for possession of the ball and in defence of their territory. Excessive physical contact is likely to be penalised, to the extent of having an offending player permanently sent off from the match, which puts the outnumbered team at a major disadvantage.

Much of the early personality research on football, incorporated generalised personality questionnaires and ill-defined opportunity samples, the problems with which have been described previously. There are however some studies of interest, which will be summarised below.

Cooper & Payne (1972) investigated seventeen football teams in the English First Division using the 'Orientation Inventory' (Bass, 1962). They found that players in the more successful teams were more focussed on personal rewards ('higher self orientation') and less orientated towards maintaining harmonious relationships, job completion, persistence and excellence (low 'interaction' and 'task-orientation') compared to players from the less successful teams.

Panda & Bisivas (1989), using an Indian sample and a translated version of the 'Eysenck-Maudsley Personality Inventory', found 'high-achieving' football players to be more extroverted, confident, anxious, emotional, tough-minded and aggressive than 'low achieving' football players. The inventory used was however a general one with a relatively large number of scales, thus increasing the likelihood of chance correlations. Also a cultural issue which limits its generalisation, is that high achieving soccer players in India would fall dramatically short of qualifying for the same category within Europe where football is played at a superior level.

Kovac (1996) uniquely considered the psychological characteristics of 'creativity' and 'creative-memory' with regards to excellence in football. He administered a figural creativity test (Urban and Jellen, 1993) as well as components of Torrance's 'Test for Creative Thinking' (Jurcova, 1984) to fifty-nine boys at a private secondary school specialising in football. Kovac concluded that not only were ratings of soccer performance and higher school grades associated with greater creativity, but also that better memory of past events was linked to inferior coping and poor self-rating of soccer performance. The latter finding has been proposed in terms of 'barrier memory': an effective mental barrier against previous failures, which enhances confidence and hence performance. This finding is refreshingly unique, however due to its uniqueness, further research needs to be performed to confirm the reliability and validity of the explanatory power of the creativity measures.

To draw conclusions regarding previous personality research on success in football, it is useful to turn to Morris (2000) who reviewed thirty years of research and concluded that no clear patterns of association have been established between personality and success in football. He maintains that this is likely to be due to the 'piecemeal and a-theoretical nature' (p.722) of previous research, citing the associated problems to include; opportunistic sampling, variations in definitions of 'success' and 'high level performance', invalid cross-sectional comparisons and a lack of statistical correction being made for multiple comparisons. His recommendations for future research to more adequately discriminate between elite and non-elite football players (of the same age) include; the use of rating scales/measures of specific constructs, which he suggests would be more sensitive than general personality questionnaires and the inclusion of qualitative methods, such as interviews, to help uncover reasons for certain psychological patterns and how they affect performance. The use of longitudinal or quasi-longitudinal designs were also highly recommended to ascertain the sustained relevance and stability of prominent psychological characteristics.

Rugby

Rugby Union is the most internationally watched and played high-contact team sport in the world. The 2003 Rugby world cup was the third single largest sports event, in the world, in terms of spectators, after the Olympics and the Football world cup.

Rugby is a field sport characterised by a large amount of physical contact between teams in 'rucks', 'malls' and 'scrums' in competition for the ball. Contact intensity is at its highest during open play, where attackers run at full speed trying to break through their opponents defensive lines, while the defenders tackle them in attempt to prevent this.

Personality research associated with rugby is extremely sparse in comparison to that of football. Hanton, Jones & Mullen (2000) compared rugby league players ('explosive') to target rifle shooters ('fine motor skill') implementing a modified version of the 'Competitive-State-Anxiety-Inventory' just prior to competition. There was a significant difference in scores, with rugby players reporting somatic and cognitive anxiety to be more facilitative, whereas rifle shooters reported it to be more debilitative. The rugby players were also found to have higher scores on self-confidence than the shooters.

Wilson and Kerr (1999) measured the affective responses to success and failure in competitive rugby players before and after losing and winning matches. Winning was found to produce a range of pleasant emotional outcomes and reductions in arousal and stress. Losing was found to produce strong unpleasant emotional changes, a reduction in arousal but no reduction in stress. Cox & Kerr (1990) also found winning rugby players to have significantly higher arousal scores and significantly lower stress scores than teams that lost, while Kerr and Van Schaik (1995) reported rugby players to feel less serious and more spontaneous after winning than after losing games. Golby, Sheard and Lavallee (2003) investigated players from various nations competing in the 2000 Rugby League World Cup. They produced evidence indicating that superior scores on 'hardiness' and 'mental-toughness' were associated with improved performance. Potgieter and Bisschoff (1990) found rugby players ('medium risk/explosive sport') to be higher sensation seekers than marathon runners ('low risk/endurance sports'). Personality research more directly associated with actual sports rank in rugby appears not to exist.

Basketball

Basketball is one of the most internationally played and watched low-contact sports in the world. Played on a court by two opposing teams of five players, points are scored by throwing the ball through an elevated horizontal hoop. Basketball is considered a low contact sport, as physical contact is rare and when it does occur, the player responsible is often penalised to the detriment of his team.

As with rugby, research regarding basketball and personality is scarce. Basketball players have been compared to a non-sport control group using the psychological inventory 'ACSI-28' and were found to score higher on the psychological variables of 'coping with adversity', 'goal-setting' and 'mental preparation' (Kioumourtzoglou, Tzetzis, Derri and Mihalapoulou, 1997). From the analysis of semi-structured interviews, Schilling & Hayashi (2001) concluded basketball players to have more socially-orientated personal incentives for achievement than cross-country athletes. Skordilis, Gavriilidis, Charitou and Asonitou (2003) gave amateur and professional basketball players, three subscales from the twenty-five-item 'Sport Orientation Questionnaire': competitiveness, win-orientation and goal-orientation. The professional players were found to have significantly higher 'win-orientation' scores than the amateurs. However as a unique finding, a replication study would be necessary to confirm this. The cohesiveness of elite university basketball teams has been strongly positively associated with their success (Carron, Bray & Eys, 2002). Maddi & Hess (1992) found that 'hardiness' scores (a composite of inter-correlated views about self and the world characterised by a sense of commitment, control and challenge) obtained from male high school first team players before the season began, were correlated to a composite measure of basketball performance throughout the season.

The omissions, inconsistencies and definitional vagueness stated earlier in this chapter of previous 'sport/personality' research have affected the validity and reliability of a large body of this work, making it problematic, if not impossible, to make comparisons and draw clear conclusions from. It is a major aim of this current study to clarify this area and to offer clear categorical distinctions and definitions to enable valid and reliable future comparisons.

After reviewing previous personality research in relation to sport participation and performance and the relationship between the sex hormone testosterone and personality as well as the issues associated with this previous research, the conclusions drawn from this chapter can be used to develop the rationale for the design of this current investigation, which will be mentioned in detail at the end of this introduction. The next chapter of this introduction is devoted to reviewing research on visual-spatial ability and in particular mental rotation ability.

Chapter 3: Visual-Spatial Ability

Visual-spatial ability can be defined as: the quality of being able to perform "tasks that involve non-verbal cognitive manipulations of objects and may include the ability to visualise how object appear when they are rotated, to detect the orientations of and the relationships between different stimuli and to correctly perceive visual patterns" (McGee, 1979, p.889). Visual-spatial ability is essential in successfully performing tasks natural to 'field' and 'team' sports. "Striking a moving opponent or ball requires fine judgement of distance. Determining the exact point of impact demands an accurate perception of the surface of the target as it moves through space, in addition to an awareness of the relative movement of one's own hand, foot, head, and so forth" (Manning, 2002b, p.128).

Visual spatial tests are regarded as highly valid and reliable measures of visual-spatial ability. These include paper and pen (and often time-limited) disembedding, predictive and mental rotation tasks. These visual spatial tasks, and in particular mental rotation, seem to produce consistent sex differences favouring males (Halpern, 1986, 1992; Wilson, DeFries, McClearn, Vandenberg, Johnson and Rashad, 1975). These differences are robust across simple or complex patterns (Bryden & George, 1990). The effect size is often quite large amounting to sixteen percent or more, depending on the tests involved (Collins & Kimura, 1997; Sanders, Soares, & D'Aquilia, 1982) and remains unchanged over years (Masters and Sanders, 1993). This current investigation will focus on mental rotation tasks.

Mental rotation Tasks

A mental rotation task is a task in which observers are required to recognise a visual target in different spatial orientations or rotations. Males are thought to perform better on mental rotation tasks either by being more accurate in their responses or by showing greater speed when completing them (Blough & Slavin, 1987; Harris 1981; Lohman, 1986). The male advantage in these tasks seems to be established by about ten years of age (Johnson & Meadle, 1987). In addition McGlone (1981) has shown that females approach tasks differently than males do by making more rotational hand movements while contemplating cognitive rotations, suggesting that women more frequently need concrete aids or verbal strategies to successfully complete such tasks (Clarkson-Smith & Halpern, 1983).

The cause of the sex difference in visual-spatial ability and in particular mental rotation, is thought to be largely, due to physiological differences in brain development and function as caused (at least partially) by pre-natal sex hormones and in particular prenatal testosterone. Geschwind and Galaburda (1985) have found repeated evidence to suggest that prenatal testosterone enhances, while prenatal oestrogen inhibits the developmental growth of the right hemisphere of the brain, responsible for good spatial abilities.

Further research evidence supports the relationship between prenatal sex hormones and mental rotation ability. Dawson (1967) administered a series of mental rotation trials to a number of West African males, all of whom suffered from a disease, which caused higher oestrogen levels than those normally found in that male population. This group of males showed significantly reduced visual-spatial ability in comparison to the non-affected males, thus suggesting that high oestrogen levels have the opposite influence on mental rotation ability to high testosterone levels.

Similar effects were found in certain South American tribes, where the males habitually chew the leaves of the coca shrub, thus releasing and ingesting cocaine. When cocaine is ingested in large quantities it decreases the secretion of testosterone. Such men showed typical signs of feminisation (including enlarged breasts and widened hips), they also demonstrated reduced mental rotation abilities similar to those of females (Dawson, 1967).

Males who produce little, or are insensitive to androgens (testosterone) also show reduced spatial abilities whereas females with high androgenisation (androstenedione levels) show greater spatial abilities (Hier & Crowley, 1982; Masica, Money, Ehrhardt & Lewis, 1969; Peterson, 1976). Spatial abilities of pregnant women (who have higher than normal levels of oestrogen) decrease relative to women who are not pregnant (Woodfield, 1984).

Grimshaw, Sitarenios and Finegan (1995) found positive correlations between prenatal testosterone measures and mental rotation ability in seven-year old girls. However findings were unclear regarding seven-year old boys.

Mental rotation and 2D: 4D

If mental rotation and other visual-spatial abilities are positively correlated with prenatal testosterone and negatively correlated with oestrogen, then it is expected that mental rotation will have significantly strong negative correlations with 2D: 4D digit ratio. This was found to be the case. A subset of seventy-eight participants, from Manning and Taylor's (2001) investigation, were tested using the 'Judgement Of Line Orientation Test' (JLOT), where subjects had to draw the line which represented the surface of water in a tilted container, and the 'Vandenberg Mental Rotation Test' (MRT), a ten minute timed test, with each question consisting of an object made of cubes containing three right angles to be compared to four other rotated objects to be judged as the same or different. As predicted lower 2D: 4D of participants correlated with better performances on the JLOT (but not significantly) as well as being highly correlated with participants MRT scores.

Sanders, Soares & D'Aquila (1982) investigated male and female participants from Liverpool, London, Sweden and Hungary to investigate the national and international variation in the expected sexually dichotic relationships between digit ratio and mental rotation performance. From all four sample groups, as predicted, the male participants were found to have lower mean digit ratios and to perform better on the mental rotation tasks. The women's scores however were a mix of negative and positive non-significant results.

It should be considered, when dealing with research from differing nationalities and cultures, that there may be significant psycho-social influences leading to a variation in performance of visual-spatial tasks, with a cultural bias towards western societies, where individuals grow up with more experience of similar tasks (e.g. children's building bricks and model-making and adults using maps and designing).

Other than the afore mentioned Sanders, Soares & D'Aquila (1982) investigation, previous research, which found low 2D: 4D digit ratio to be associated with high mental rotation scores as well as high levels of attainment in a number of sports (Manning and Taylor, 2001) appears to only have been performed on a male-only participant base. One aim of this current investigation is to see if 2D: 4D digit ratio and mental rotation ability are both indicative of athlete achievement rank in female sport participants also. As a result, this current investigation will include equal numbers of female and male participants to see if this correlation is replicated for female participants and also to make gender comparisons on all of the measured 'predictor variables'.

Chapter 4: Proposed investigation

Overview of Study design

Participants

This current investigation will incorporate participants from clearly defined categories of high-rank and low-rank participation in low-contact, semi-contact and high-contact team sports as well as from a non-sport participant control group.

Low-contact sport participants will be taken from basketball teams, semi-contact sport participants from football teams and high-contact sport participants from rugby (League and Union) teams. All participants must participate (training/playing) in their sport at least once a week to qualify for their specific category.

For the three previously mentioned sports categories, participants will be further categorised as either 'high rank' or 'low rank' players. A high rank participant is one who scores between level six (has competed at county level) and level ten (has represented their country) on the Manning and Pickup (1998) 'Sports Performance Questionnaire', indicating that they have participated at a serious-to-elite standard. Low-rank participants, are those that score between level two (sport is only social) and level five (believe they are able to compete at county level), thus indicating that they have participated at a social-to-non-elite standard. The non-sport participants (control group) will score at level one and will be people who do not participate regularly (less than once a week) in any individual or team sports.

Approximately equal numbers of participants in all four of the participant 'sport contact intensity categories (including control group) were included, with approximately equal number of sexes within each group (to allow for possible sex comparisons).

Secondary variables to be controlled in this current study

Certain extraneous or 'secondary' variables, considered to have possible influences upon the correlations between the predictor variables and athlete achievement rank (but not of direct interest to this current investigation) were recorded, so if their misleading influences did occur, the effects could be removed in statistical analysis. These variables were measured by issuing each participant a 'participant information sheet', which enquired about the following variables:

Ethnic origin:

Data were gathered regarding the ethnicity of the biological mother and father of all the participants from three possible ethnic categories: Caucasian, Asian or Afro-Caribbean. Therefore the following combined parental ethnicities were possible: Both parents Caucasian, both parents Asian, both parents Afro-Caribbean, one parent Asian and one parent Caucasian, one parent Asian and one parent Afro-Caribbean and finally one parent Caucasian and one parent Afro-Caribbean. This is to account for the possible influences of ethnic variations, which occur in digit ratio, as mentioned earlier in chapter two (Manning et al, 2000a).

Age:

All participants had to be within the relatively select age category of eighteen to twenty-five (approximately). Age was controlled for a number of reasons: It has been found to be positively correlated with athlete achievement rank in a number of sports

(Manning & Vella, unpublished). It is also necessary to compare participant groups of similar ages, as some personality traits, such as extroversion, neuroticism, and psychotocism all decrease with age from a high at late puberty (Eysenck, 1970). Circulating testosterone decreases among males from the early twenties onwards; with men showing more pronounced declines associated with age than women (Zuckerman, 94). Even though this study is concerned with prenatal testosterone, it would be of obvious benefit to account for free testosterone concentrations as a possible confounding influencing variable. Many published data do not take age into account, making valid comparisons with other research impossible and attempted conclusions suspect.

Number of years participating:

The length of time an athlete spends playing and training for a sport has a large influence upon their success and thus achievement rank. The longer you have played and trained, the more skill and ability your can acquire which has been found to differentiate experts from novices in sport (Paull and Glencross, 1977). As a result participants will be asked how many years they have participated in their sport, so that the possible extraneous influences of this variable can be monitored and removed if necessary during data analysis.

Number of hours spent training and playing per week:

This is also expected to have a possible influence upon the participants' achievement rank. Halvari (1989) reported that training and playing intensity explained eighteen percent, thirty percent and thirty-six percent of the variation in sports success at local, regional and national levels respectively, revealing its increased importance at the higher levels of sports. As this is not a variable with which the current study is directly concerned, its possible effects on athlete achievement rank and associated correlations will again be monitored and removed if necessary.

Height:

The participants will be asked their height, as this can be of obvious benefit in all of the sports tested. Height is advantageous in football for defending and competing for a high ball against opposition members, in rugby for lineout jumping and again competing for high balls and particularly in basketball for shooting and defending. Singer and Janelle (1999) as well as Cowart (1987) recognised height as well as other physical attributes as a major determining factor for potential success in sport. The possible influence of height on athlete achievement rank and its associated correlations with other predictor variables will therefore be monitored and if necessary, removed.

Weight:

In some sports, particularly rugby, the weight of a player is important in regards to elite performance, as it directly related to muscle mass, which is a physical attribute with strong associations with potential for success in sport (Singer and Janelle, 1999; Cowart, 1987). The heavier a player in rugby, the more momentum they can create and the greater success they can achieve in contact situations such as tackling, scrummaging, rucking and malling. In consequence, if there are two players of equal skill, the heavier and more muscular player will often be selected. The possible effect of players' weight on athlete achievement rank and its associated correlations with predictor variables will therefore be monitored and if necessary, be removed.

Finger Injuries:

The participants will also be asked if they have suffered any injuries in the past to any of the fingers of their right hand (the hand from which the digit ratios will be measured). Physical injuries to the second and fourth digits, such as broken fingers or severed ligaments and tendons, may compromise accuracy of the participants' 2D: 4D measurements as effective markers of prenatal testosterone and oestrogen concentrations. Participants will be excluded from the investigation with such injuries to the second and fourth fingers of their right hand to maintain the reliability and validity of such measurements.

Predictor variables to be investigated in this current study

This current study is concerned with investigating the correlations among the predictor variables and between these variables and athlete achievement rank. Individual descriptions and rationales for the specific mental rotation test, personality inventory and the personality variables selected for use, are as follows:

Mental Rotation Test:

The Philips and Rawles (1976) timed mental rotation test was chosen to test the participants' visual-spatial ability. It is a twenty item test where for each item, participants have to compare two shapes made up of cubes and three right angles at different rotations and decide if they are in fact the same or different. The Philips and Rawles test was favoured over two other established mental rotation tests (of virtually identical format): the Shepard and Metzler test (1971) and the Vandenberg and Kuse test (1978), as all are of similar reliability and validity, however the Philips and Rawles test only takes two minutes to administer in comparison to the other tests, which take significantly longer (fifteen and ten minutes respectively). Its brevity makes the Philips and Rawles test highly advantageous for data collection in this particular investigation, given that the participants will also have their digit ratio measurements taken, be given a personality inventory and a participant information sheet, all of which must be completed within a limited time period (before or after matches or training-sessions).

Personality Inventory:

The personality inventory chosen for this current investigation was Tellegen's (1982) Multidimensional Personality Questionnaire (MPQ). The full MPQ has two-hundred-and-seventy-six items loading on eleven primary traits and which can be categorised under three higher order factors: 1) Positive affectivity: primarily associated with well-being, social potency and achievement, 2) Negative affectivity: primarily associated with stress-reaction, alienation and aggression and 3) Constraint: primarily associated with harm avoidance, control and traditionalism.

The MPQ is a factor analytically developed self-report instrument. The structure formed by the MPQ dimensions is clear and replicable and is thought to be conceptually informative. Its measures have acceptable internal consistencies and retest reliabilities and are meaningfully related to other test and non-test variables (Tellegen, 1982). "The MPQ provides for a fine grained analysis of personality by measuring a range of discrete trait dispositions at the lower order level" (Patrick, Tellegen and Curtin, 2002, p.150). There are low correlations among MPQ scales, showing the distinctiveness of the associated trait concepts.

With regards to the validity of the MPQ, Harkness, Tellegen and Waller (1995) investigated two-hundred-and-thirty-two participants, correlating their MPQ scores with self-reports and observer ratings. They concluded that "substantial evidence exists for relationships between MPQ personality scales and indices of overt behaviour" (p.185). Kamp (1986) also found substantial correlations between the MPQ scores of participants and the frequency of the specific traits they described when comparing participant scores with personal biographical diaries.

Four subscales, taken in full from the MPQ, will be incorporated into the study. The subscales are as follows: 'Social-potency', 'Achievement', 'Control' and 'Harm-avoidance'. These subscales were chosen as previous literature has shown them (or personality variables they are known to subsume), to either correlate with sports success/athlete achievement rank or with sport contact intensity (positively or negatively) as well as showing marked sex differences that may be associated with differing concentrations of the prenatal sex hormones. The personality descriptions associated with high and low scores for these four MPQ subscales are described below in table 1 (as taken from a confirmed-perspective cluster analysis derived from item-content sortings by nine to twelve judges) (Tellegen, 1991).

Table 1:
Tellegen's content summaries of the four subscales used in this current study

Scale	Self descriptions of high scorers	Self descriptions of low scorers
Social potency	Is forceful and decisive; is persuasive and likes to influence others; enjoys or would enjoy leadership roles; takes charge of and likes to be noticed at social events.	Prefers others to take charge and make decisions; does not like to persuade others; does not aspire to leadership; does not enjoy being the centre of attention.
Achievement	Works hard; likes long hours; enjoys demanding projects; persists where others give up; puts work and accomplishments before many other things; is a perfectionist.	Does not like to work harder than is strictly necessary; avoids very demanding projects; sees no point in persisting when success is unlikely; is not terribly ambitious or a perfectionist.
Control	Is reflective; is cautious, careful, plodding; is rational and sensible; likes to anticipate events; likes to plan their activities.	Is impulsive and spontaneous; can be reckless and careless; prefers to play things by ear
Harm avoidance	Does not enjoy the excitement of adventure and danger; prefers safer activities even if they are tedious and aggravating.	Goes for risky stunts and adventures; may enjoy the excitement of a dangerous emergency or disaster; might expose self to possible attack or injury.

The four MPQ personality subscales to be used in this current investigation have been extensively compared to other personality inventories and their subscales for possible correlations (Patrick, Curtin and Tellegen, 2002). Some of the findings are as follows:

Social Potency:

The MPQ subscale of social potency was found to correlate highly with the California Psychological Inventory's (Nichols & Schnell, 1963) scales of 'dominance' (correlation of .70 for females and .67 for males), 'capacity for status' (.45 and .31), 'sociability' (.60 and .51), 'social presence' (.46 and .22) and 'self-acceptance' (.56 and .52). Social potency is also correlated with the 'extroversion' subscale from the 'Eysenck Personality Questionnaire' (1964) (.57 for females and .60 for males) and with the complete version of Raskin & Terry's (1988) 'Narcissistic Personality Inventory', with an overall correlation of .60.

Achievement

The MPQ subscale of achievement was found to moderately correlate with the California Psychological Inventory's subscales of 'dominance' (.32 for females and .28 for males), 'sociability' (.28 and .13), 'good impression' (.33 and .05), 'achievement via conformance' (.41 and .20) and 'psychological mindedness' (.31 and .16). Achievement also correlated with the 'Emotionality-Activity-Sociability Temperament Survey's (Buss & Plomin, 1984) subscale of 'activity' with an overall correlation of .31.

Harm avoidance

The MPQ sub-scale of harm-avoidance was negatively correlated with Zuckerman's (1979) 'Sensation Seeking Scale' with an overall correlation of -.36 and was uniquely and highly associated with 'fearfulness' on the 'Fear Survey Schedule III' (Arrindell, Emmelkamp and Van Der Ende, 1984). Moderate correlations also occurred between harm-avoidance and the California Psychological Inventory's subscales of 'responsibility' (.33 for females and.11 for males), 'self-control' (.35 and .00) and 'femininity' (.43 and .23).

Control

The MPQ subscale of control was found to be negatively correlated with the Eysenck Personality Questionnaire's subscale of 'psychotocism' (-.45 for females and -.28 for males), the California Psychological Inventory's subscale of 'flexibility' (-.44 and -.55) and the Emotionality-Activity-Sociability Temperament Survey's subscale of 'impulsivity' (overall –.52). Control also has strong positive correlations with the California Psychological Inventory's subscales of 'self-control' (.47 and .23) and 'achievement via conformance' (.49 and .32) and more moderate correlations with the California Psychological Inventory's subscales of 'responsibility' (.29 and .02), 'good impression' (.36 and .14) and 'communality' (.39 and .27).

For this current investigation, the full items for these four subscales were extracted in their entirety with all questions and instruction replicated verbatim from Tellegen's (1982) Multidimensional Personality Questionnaire. All the items were then randomly assorted in preparation for presentation to the participants.

Proposed Model

In this thesis I will propose and test a model of some of the most prominent contributors to 'athlete achievement rank', i.e. the level at which an athlete competes. This investigation seeks to replicate correlations within the sport psychology domain, such as the relationship between low 2D: 4D digit ratio and high athlete achievement rank, (particularly for the previously untested female population) as well as investigating the associations between mental-rotation ability and specific personality traits with athlete achievement rank. Past research indicates that these factors are associated with sport success. The aim of this research is to examine both the unique proportionate influence of these variables and, more importantly, their interaction in explaining sporting achievement. The proposed model is presented below in figure one.

Figure 1
Model of proposed influences of predictor variables, and their relative interactions, on athlete achievement rank

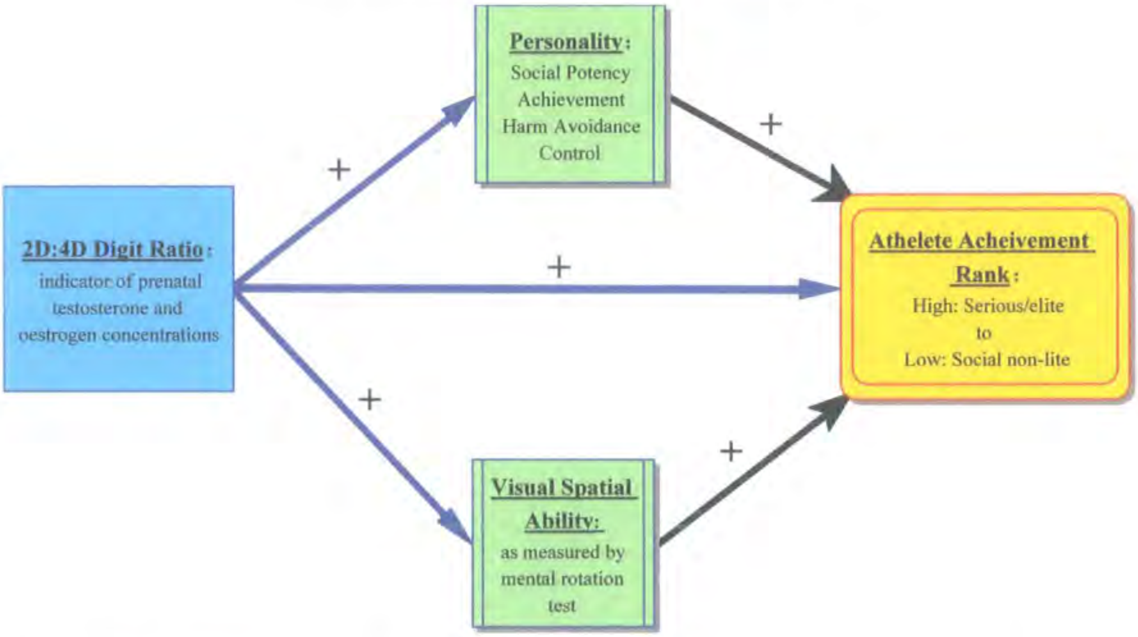


Figure one illustrated above, proposes the following relationships/interactions between the variables involved in this current investigation: A sport participant's relative concentrations of prenatal testosterone and oestrogen, as represented by their 2D: 4D digit ratio, will not only directly influence their 'athlete achievement rank', but will also influence the specific personality variables of 'social potency', 'achievement', 'harm avoidance' and 'control' as well as their mental rotation ability. These variables in turn will again have an influence on the participant's achievement rank. It is also proposed that the participant's sex as well as the contact intensity of the sport they play, will also influence their scores for 2D: 4D digit ratio, the specific personality variables and mental rotation. The model finally suggests that the relationship between digit ratio and achievement rank is at least partially mediated by the influences of mental rotation ability and the specific personality variables (as well as other possible secondary variable influences, such as: height, weight, ethnicity and years spent playing sport).

Research Hypotheses

This current investigation will make the following hypotheses:

- **H1)** 2D: 4D digit ratio will be negatively correlated with athlete achievement rank.
- **H2)** 2D: 4D digit ratio will be negatively correlated with mental rotation scores.
- **H3)** Mental rotation scores will be positively correlated with athlete achievement rank.
- **H4)** The personality variable: 'social-potency' will be negatively correlated with 2D: 4D digit ratio and positively correlated with athlete achievement rank.
- **H5)** The personality variable: 'achievement' will be negatively correlated with 2D: 4D digit ratio and positively correlated with athlete achievement rank.
- **H6)** The personality variable: 'harm-avoidance' will be positively correlated with 2D: 4D digit ratio and negatively correlated with sport contact intensity.
- **H7)** The personality variable: 'control' will be positively correlated with 2D: 4D digit ratio and negatively correlated with sport contact intensity.
- **H8)** Male sports participants will have lower 2D: 4D digit ratios and higher mental rotation scores than female sports participants.

- **H9)** Male sports participants will score higher on the personality variables: 'social-potency' and 'achievement' and lower on the personality variables: 'control' and 'harm-avoidance' than the female sports participants.
- **H10)** The expected negative correlation between 2D: 4D digit ratio and athlete achievement rank will be (partially) mediated by the mental rotation and the personality variables.
- **Research Question)** To investigate the stability of the proposed model of influences on achievement rank, across the moderating variable influences of participant sex and sport contact intensity.

Method

Participants

Participants were all current students at universities in the north east of England (Durham, Northumbria, Newcastle and Sunderland). Sports players were selected if they were regular competing and training members (minimum of once per week) of university/college sports teams for rugby (League and Union), basketball or football. The non-sport participant control group were also current university students selected if they played no regular team or individual sport (less than once a week). Activities not included in this criteria included non-competitive health and fitness pursuits, such as jogging, cycling, aerobics and weight training.

Emails were sent to the addresses of team coaches and captains, which were obtained from athletic union offices and web sites, informing them of the purpose of the current study and asking if they could "discuss with the players if they would be prepared to participate" in the current investigation. Out of the eighteen teams contacted, twelve replied, confirming they would be prepared to participate, and subsequently appropriate dates were organised to administer the tests and questionnaires (all before or after training sessions or matches). The non-sport playing control group participants were volunteers recruited from classes and workshops from different academic departments from the various universities.

Table 2 overleaf shows the number of participants used in this current study, categorised by both sex and sport (rugby, football, basketball and non-sport) as well as showing the overall number of male, female and combined sex participants.

Table 2:
Participant sizes, categorised by both sport and sex

Sports Teams	Male	Female	Combined
Rugby	27	25	52
Football	23	31	54
Basketball	23	26	49
Non-sport ctrl	21	23	44
Overall Total	94	105	199

The mean age of the participants was 20.17 years with their age ranging from 18 to 25 years. The parental ethnicities of all of the participants were recorded, each being drawn from three possible ethnic categories (Caucasian, Asian and Afro-Caribbean). The combined parental ethnicities of all the participants are shown in Table 3 below, which reveals the vast majority of participants (over 90%) to be Caucasian (with both their biological parents being Caucasian).

Table 3:
The combined parental ethnicity of the participants

Combined Parental Ethnicity	No of Participants
Both parents Caucasian	184
1 parent Asian, 1 parent Caucasian	7
Both parents Asian	5
Both parents afro-Caribbean	3

Withdrawn or removed participants

No participants actively withdrew from the current investigation. Seven participants' results, however, were later removed from the study, as being considered unreliable or invalid. Three participants' results were removed due to having damaged right hands, which may have compromised their 2D: 4D digit ratio measurements. Their injuries included a badly broken finger, lacerations causing nerve damage and a torn finger tendon (all injuries affecting either the second or fourth digit of the right hand). Another four participants were removed, two who could not understand the questionnaire due to a limited knowledge of English and two participants were considered not to be attending to the test/questionnaire seriously enough (as observed from their inappropriate behaviours in test conditions).

Apparatus and instruments

A standard stopwatch was used to time the mental rotation test during the testing period. A standard photocopier was used to make copies of the participants' right hand palms and electronic digital callipers (with a resolution of 0.01mm, an accuracy of 0.03mm and a repeatability of 0.01mm) were used after the testing, to measure the participant's digit lengths from the photocopies taken of their hands.

Material and Procedure

Data collection:

The participants were given a verbal briefing (a printed copy of which was also given to every participant to keep, see Appendix 1). This explained the nature of the current investigation, the testing format and procedure, the confidentiality of participants' data and the participants' right to withdraw from the investigation at any time. The briefing sheet also contained the investigators email address to allow contact after the testing, if any subsequent questions arose. The participants were then asked if they had any questions regarding the study, which were duly answered. The participants were then asked to read and complete the consent form (see Appendix 2). The participants were then given the Philips and Rawles (1976) 'Mental Rotation Test' (see Appendix 3). The participants were notified of the time limit, were shown two example questions and were instructed to perform the task as "quickly and as accurately as possible". They were given two minutes to answer as many of the twenty questions as they could. After the time limit was exceed, the test sheets were collected and sealed in separate brown paper envelopes. The participants were then given a participant information sheet to complete (see Appendix 4). On this sheet, they gave personal information about themselves (age, weight, height, ethnicity) and their sport, where applicable (hours training per week, years played) and they then rated themselves on a sports achievement rank scale (Manning and Pickup, 1998) between one and ten, with one representing non-sports participation and ten representing international sports representation. These documents were then collected and sealed in another set of different brown paper envelopes. Finally the participants were given a personality inventory to complete (see Appendix 5), with questions taken from four of the total eleven subscales of Tellegen's Multidimensional Personality Questionnaire (1982). These subscales were 'Social-Potency', 'Achievement', 'Control' and 'Harm-Avoidance'. The questionnaire was composed of fifty-one items "used to describe attitudes, opinions, interests and other characteristics". The participants were asked to either indicate their agreement or disagreement with each statement or to choose one of two statements which best described their disposition. The questionnaire instructed participants to "Please answer every statement, even if you are not completely sure of the answer" and to "Read each question carefully, but do not spend too much time deciding on the answer". They were notified that there was no time limit for the completion of the inventory. After the inventories were completed they too were collected and sealed in a separate set of brown paper envelopes. The participants were then taken to a nearby photocopier, where they had the palm of their right hands photocopied. If necessary, participants were asked to remove rings. The brightness setting of the photocopier was adjusted for optimum clarity of the hand creases and fingertips.

The participants were thanked for their time and effort and were told they would receive a copy of the 'research findings sheet' (see Appendix 6), which was duly mailed to the team coaches and captains to distribute to the players after the investigation was completed.

Data coding

Once the data collection was completed, the 2D: 4D digit ratio of the right hands of all the participants was measured from the photocopies using digital callipers. Measures were made from the central point of the tip of the second finger to the central point of the basal crease of the second finger and divided by the same measure from the fourth finger. An example of a participant hand photocopy and the subsequent measurements and calculations made is presented in Appendix 7.

The mental rotation tests and personality inventories were scored using acetate overlay sheets. All the participants' data, including that from the 'participant information sheets', were coded and entered into an SPSS statistical programme on a personal computer ready for data analysis.

Results

Much of the previous psychological research associated with athletic participation, has compared *either* non-sport participants with sport participants *or* elite sports participants with non-elite sports participants, on a number of different variables. In this current investigation it was decided to incorporate both a non-sport participant control group and sport participants of varying ability so that comparisons could be made between these different populations simultaneously to allow more elaborate conclusions to be drawn as to their characteristic differences/similarities on specific variables.

Much previous research comparing sports persons with non-sports persons has implicitly assumed that non-sport players do not participate because they are poor at sport and hence will score lower on variables that are associated with sporting ability and rank. There seems to be no strong grounds for this assumption. Lack of involvement in sport may result from a variety of factors that are unrelated to potential sporting ability such as the lack of opportunity (facilities, coaching), parental influence and other leisure interests (Singer and Janelle, 1999). If this is the case, studies that compare non-sports participants with those who play sport are unlikely to find significant differences and this may account for the paucity of consistent results in studies using this design. There are important implications of null results for the present study. It would mean that inclusion of the non-sport playing control group in further analyses would obscure differences between high and low rank sport participants. It should also be noted that the members of the non-sport participant control group may not be representative of the general population for their age range (eighteen to twenty-five years) especially the male participants. It may be quite unusual for young British males of this age not to take part in some form of sports activity on a regular basis, as proposed by Holt (1989).

The important variables thought to influence sporting achievement in this current investigation will be categorised as 'predictor variables' as they have been hypothesised to be correlated with the athlete achievement rank of the sport participants. These predictor variables include the primary variable 2D: 4D digit ratio and five other variables which are hypothesised, not only to be correlated with rank, but also to mediate the correlation between digit ratio and rank. These variables are: mental rotation and the four personality variables: social-potency, achievement, control and harm-avoidance. Participant sex and sport contact intensity are two variables that may condition the correlations between the predictor variables and athlete achievement rank and thus will be categorised as 'moderating variables'. The extent to which the relationship between the predictor variables and rank varies, as a function of the moderating variables will be investigated. A number of other variables considered to have possible influences upon rank and its correlations with predictor variables will also be investigated, these will include: parental ethnicity, weight, height, hours trained/played per week, years played and age. These variables will be called 'secondary variables' and will not be included in the final model. Their measurements will be taken in case their effects moderate correlations between the predictor variables (particularly digit ratio) and achievement rank and therefore need to be partialed out in statistical analysis.

Analysis 1: Differences between sports and non-sports players and between low and high rank sport players

The aim of this analysis was to compare the high rank sport participants with the low rank sport participants of all three of the different sports and also to compare the combined sports participants of varying ability with the non-sport playing control group on all of the dependent variables. It was in essence a between group comparison. To do this, the continuous variable of sport rank was dichotomised into low and high rank. Those coded as low rank had a score between level two ('Your sport is only social') and five ('You could compete at county level') on the ten-point rank criteria scale, indicating that they played sport at a social-to-non-elite level. Those coded as high rank had a score between level six ("You have competed at county level") and ten ("You have represented you country"), indicating that they played sport at a serious-to-elite level. The non-sport participants by definition had a score of zero on the sport rank measure. These three groups constituted three levels of the independent variable in a series of one-way analyses of variance. (Chi square analysis was used for nominal data i.e. parental ethnicity).

A series of one-way ANOVA's were performed twice for each dependent variable. The first analysis included the non-sport participant control group, in order to examine whether non-sport participants differ from both high and low ranking sport players in relation to physiological, psychological and mental variables. It corresponds to studies in the existing literature where the design is essentially sports participants versus non-sports participants. Following analyses of these data, it will be decided whether to omit the control group from subsequent analyses if they do not differ significantly from the sports participants, as their data may occlude important and significant effects between sports participants of different abilities.

The second series of one-way ANOVA's omitted the non-sport participants in order to examine differences between the low and high sporting ranks in relation to all the dependent variables. It corresponds to studies in the existing literature where the comparison is between elite and non-elite sports participants in relation to physiological, psychological and mental variables. This is of interest in itself, but a key question for the present study is the extent to which these two analyses produce conflicting results.

Table 4 (overleaf) presents the means and standard deviations, while table 5 (overleaf) presents the values for the inferential statistics, comparing low-rank sport participants, high-rank sport participants and the non-sport participants on the dependent variables. The findings are as follows:

Findings

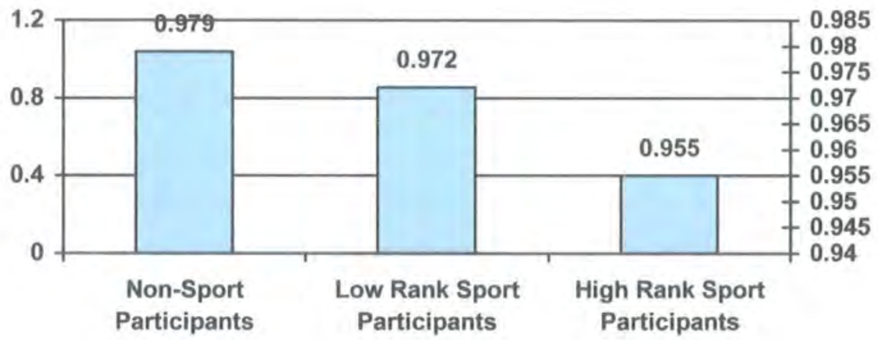
The findings regarding the predictor variables are as follows:

Digit Ratio:

With the non-sport participants included, there was a significant difference between the three groups on digit ratio ($F(2, 196)=15.385$, $p<.001$) which explained 13.6 % of variance in athlete achievement rank. Inspection of the means indicated that the values followed the hypothesis; that low 2D: 4D digit ratio was associated with greater achievement rank. Bonferroni post-hoc tests revealed that the high-rank sport participants' indeed had significantly lower digit ratios than both the non-sport participants ($p<.001$) and the low-rank participants' ($p<.001$). The difference between low rank and non-sport participants was not significant. When the non-sport participant group was excluded from analysis, the effect remained significant between the low and high rank sport participants ($F_{(1,153)}=21.195$, $p<.001$) explaining a slightly reduced 12.2 % of the variance in the players' achievement rank.

The primary predictor variable of digit ratio was found to significantly discriminate high rank sport participants from both low rank sport participants and non-sport participants. A bar chart comparing the mean 2D:4D values of non-sport participants, low rank sport participants and high rank sport participants is presented below in Figure 2.

Figure 2
Bar chart comparing the mean 2D:4D values of non-sport participants, low rank sport participants and high rank sport participants



Results: Analysis 1

Table 4:
The means and standard deviations for sport rank differences (with inclusion/exclusion of the non-sport group)

Dependent Variables	Design	Non sport participants	Low rank sport participants	High rank sport participants	Combined Rank: means &S.D
Digit ratio	With controls	M=.9789 Sd=.02680	M=.9721. Sd=.02296	M=.9550. Sd=.02170	M=.9684 Sd=.02514
	Without	[redacted]	As above	As above	M=.9654 Sd=.02390
Harm Avoidance	With controls	M=6.4091 Sd=2.27543	M=5.6064 Sd=2.91167	M=5.8033 Sd=3.11887	M=5.8442 Sd=2.85524
	Without	[redacted]	As above	As above	M=5.6839 Sd=2.98645
Social Potency	With controls	M=8.2727 Sd=2.95992	M=7.1702 Sd=4.09468	M=9.0000 Sd=3.36650	M=7.9749 Sd=3.72331
	Without	[redacted]	As above	As above	M=7.8903 Sd=3.91727
Achievement	With controls	M=7.2045 Sd=3.20305	M=7.0851 Sd=3.21174	M=7.5246 Sd=2.91894	M=7.2462 Sd=3.11313
	Without	[redacted]	As above	As above	M=7.2581 Sd=3.09763
Control	With controls	M=7.5682 Sd=3.69410	M=7.0532 Sd=3.93869	M=7.4098 Sd=3.63491	M=7.2764 Sd=3.78180
	Without	[redacted]	As above	As above	M=7.1935 Sd=3.81402
Mental Rotation	With controls	M=11.0000 Sd=4.02319	M=12.1489 Sd=3.91017	M=10.8525 Sd=3.15614	M=11.4975 Sd=3.75496
	Without	[redacted]	As above	As above	M=11.6387 Sd=3.67668
Parental Ethnicity	With controls	Cauc=86.4% Non=13.6%	Cauc=94.7% non=5.3%	Cauc=93.4% Non=6.6%	Cauc=92.5% Non=7.5%
	Without	[redacted]	Cauc=94.7% non=5.3%	Cauc=93.4% Non =6.6%	Cauc= 94.2% Non=5.8%
Weight (KG)	With controls	M=65.9589 Sd=11.51315	M=68.4894 Sd=10.69795	M=74.5902 Sd=13.90129	M=69.7999 Sd=12.3395
	Without	[redacted]	As above	As above	M=70.8903 Sd=12.3832
Height (cm)	With controls	M=173.7777 Sd=10.61892	M=172.7149 Sd=9.55987	M=177.2787 Sd=9.65597	M=174.3488 Sd=9.9826
	Without	[redacted]	As above	As above	M=174.510 Sd=9.82448
Hours trained/played	Without	[redacted]	M=2.1383 Sd=.89924	M=3.0164 Sd=1.24488	M=2.4839 Sd=1.13019
Years played	Without	[redacted]	M=5.6468 Sd=4.57334	M=9.9426 Sd=4.66110	M=7.3374 Sd=5.05256
Age	With controls	M=21.8864 Sd=1.80717	M=20.2553 Sd=1.30290	M=20.5738 Sd=1.33490	M=20.7136 Sd=1.56778
	Without	[redacted]	As above	As above	M=20.3806 Sd=1.32052

Table 5:
The values for inferential statistics for sport rank differences (with inclusion/exclusion of the non-sport group)

Dependant Variables	Design	*F* rank	Eta² Rank	Direction of effect for sig relationships (Bonferroni used for 3 levels or more)
Digit ratio	**With controls**	$F(2, 196)=15.385. p<.001$	.136	Control sig higher than high rank. $p<.001$ Low rank sig higher than high rank. $p<.001$
	Without controls	$F(1,153)=21.195. p<.001$	.122	low rank sig higher than high rank
Harm Avoidance	**With controls**	$F(2,196)= 1.196$ (ns)	.012	N/A
	Without controls	$F(1,153)=.160$ (ns)	.001	N/A
Social Potency	**With controls**	$F(2,196)=4.828. p<.01$	.047	High rank is sig higher than low rank. $p<.01$
	Without controls	$F(1,153)=8.463. p<.005$	.052	High rank is sig higher than low rank. $P<.005$
Achievement	**With controls**	$F(2,196)=.371$ (ns)	.004	N/A
	Without controls	$F(1,153)=.743$ (ns)	.005	N/A
Control	**With controls**	$F(2,196)=.330$ (ns)	.003	N/A
	Without controls	$F(1,153)=.322$ (ns)	.002	N/A
Mental Rotation	**With controls**	$F(2,196)=2.749.$(ns)	.027	N/A
	Without controls	$F(1,153)=4.711. p<.05$	.030	Low rank sig higher than high rank
Parental Ethnicity	**With controls**	X_2 (2)=3.096 (ns)	.00756	N/A
	Without controls	X_2 (1)=.104 (ns)	.00067	N/A
Weight (Kg)	**With controls**	$F(2,196)=7.753. p<.005$	.073	Control sig lower than high rank. $p<.005$ Low rank sig lower than high rank. $p<.01$
	Without controls	$F(1,153)=9.473. p<.005$	.058	Low rank sig lower than high rank. $p<.01$
Height (cm)	**With controls**	$F(2,196)=4.082. p<.05$	.040	Low rank sig lower than high rank. $p<.05$
	Without controls	$F(1,153)=8.365. p<.005$	.052	Low rank sig lower than high rank. $p<.05$
Hours trained/played	**Without controls**	$F(1,153)=25.948.P<.001$	.145	High rank is sig higher than low rank. $p<.001$
Years played	**Without controls**	$F(1,153)=32.151. p<.001$	.174	High rank is sig higher than low rank. $p<.001$
Age	**With controls**	$F(2,196)=19.698. p<.001$	.167	Control sig higher than high rank. $p<.001$ Control sig higher than low rank. $p<.001$
	Without controls	$F(1,153)=2.168$ (ns)	.014	N/A

Harm avoidance:

It was hypothesised that high-rank sport participants would have lower 'harm avoidance' scores than the low-rank sport participants. The non-sport participants were expected to have the highest score of all. Although, when observing the relevant means, the non-sport participants were indeed found to have the highest mean score, it was the low-rank sport participants rather than the high-rank sport participants that had the lowest mean score. The between group differences were not significant, either with the non-sport participants included ($F_{(2,196)}$=1.196, n.s.) or excluded ($F_{(1,153)}$=.160, n.s.) from the analysis.

The MPQ subscale of harm-avoidance was not found to significantly distinguish between either non-sport and sport participants of high-rank and low-rank sport participants.

Social potency:

It was hypothesised that high-rank sport participants would have higher social potency scores than the low-rank participants. The non-sport participants were expected to have the lowest score of all. With the non-sport participants included in the analysis, the between group difference was significant ($F_{(2,196)}$=4.828, p<.01) explaining 4.7 % of variance in athlete achievement rank. Bonferroni tests revealed the high rank sport participants to score significantly higher than the low rank participants (p<.01), but that there was no significant difference between both the low rank and the high rank sport participants with the non-sport participants. When the non-sport participants were excluded from analysis, the effect of social potency was still significant between the low rank and high rank sport participants ($F_{(1,153)}$ =8.463, p<.005) with an improved explanatory power of 5.2 % of the variance in athlete achievement rank

The MPQ subscale of social-potency was indeed significantly higher for high-rank sports participants than low-rank sport participants with no significant differences found between sport and non-sport participants.

Achievement

It was hypothesised that high-rank sport participants would have higher 'achievement' scores than the low-rank participants. The non-sport participants were expected to have the lowest score of all. Inspection of the means showed the high-rank sport participants to indeed score higher than the low rank and non-sport participants but surprisingly the lowest mean scores were for the low-rank sport participants. These differences were not found to be significant either with ($F_{(2,196)}$=.371, n.s.) or without ($F_{(1,153)}$=.743, n.s.) the non-sport participant control group included in the analysis.

The MPQ subscale of achievement was not found to significantly discriminate between either non-sport and sport participants or high-rank and low-rank sport participants.

Control:

No predictions were made regarding the relationship between the personality variable of 'control' with sports participation and rank. Inspecting the means revealed the non-sport participants to have the highest scores and the low-rank sport participants to have the lowest scores. The mean scores for the high-rank sport participants, therefore mediated between the two. These differences were not found to be significant either with the non-sport participants included in ($F_{(2,196)}$=.330, n.s.) or excluded from ($F_{(1,153)}$=.322, n.s.) the analysis.

The MPQ subscale of control was not found to significantly distinguish between either non-sport and sport participants or high-rank and low-rank sport participants.

Mental Rotation:

It was hypothesised that high-rank sports participants would have higher mental rotation score scores than the low-rank sport participants. The non-sport participants were expected to have the lowest score of all. Inspection of the means actually showed that the high-rank sport participants scored the lowest while the low-rank sport participants scored the highest. The mean score for the non-sport participants therefore, fell between the two. With the non-sport participants included in analysis, between group differences were not significant ($F_{(2,196)}$=2.749, n.s.), however when they were excluded, the difference between the two sports ranks was significant ($F_{(1,153)}$=4.711, p<.05) explaining 3 % of variance in athlete achievement rank.

Surprisingly and contrary to hypothesised, high-rank sports players performed significantly worse on mental rotation tasks than the lower ranked players. This unexpected finding will be addressed in detail later in this investigation.

The findings regarding the secondary variables are as follows:

Parental Ethnicity:

The majority of participants had parents who were both Caucasian (over ninety percent). The non-Caucasian participants of different categories were so few that in order to perform valid statistical analysis, all non-Caucasian participants (defined as at least one Asian or Afro-Caribbean parent) were blocked together into a single category (non-Caucasian) and directly compared to the Caucasian participants (both parents Caucasian). A Chi square test was used to investigate the correlation between ethnic membership and athlete achievement rank. No hypothesis was made as to the possible association. This is because, although ethnicity is considered an important factor in terms of prenatal testosterone and 2D: 4D, as well as physiological predisposition to sporting excellence, the full extent of its influence, is not as yet fully known due to limited research in this field. As a potential influencing variable it was still deemed beneficial to investigate its effects. Although slightly more non-Caucasian participants were found in the high-rank than in the low-rank sport participant group, the largest proportion of non-Caucasian participants was found in the control group. The group differences were not found to be significant either with the controls included ($X_2(2)$=3.096, n.s.) or excluded ($X_2(1)$=.104, n.s.) from the analysis.

Participant ethnicity was not found to be a significant discriminator between either non-sport and sport participants or high-rank and low-rank sport participants.

Weight (Kg):

It was expected that high-rank sport participants would weigh more than the low-rank sport participants, who would in turn weigh more than the non-sport participants, as a result of increased muscle mass associated with intensity of sports specific training and increased height associated with elite athleticism. The means scores were found to be in the predicted direction with the differences between the groups found to be significant ($F_{(2,196)}=7.753$, $p<.005$). Participant weight explained 7.3 % of the variance in athlete achievement rank. Bonferroni tests were performed which revealed that the non-sport participants ($p<.005$) and the low-rank sport participants ($p<.01$) weighed significantly less than the high-rank sport participants. The non-sport participants were not significantly different in weight from the low-rank sports participants. When the non-sport participants were omitted, the effect between the two sports ranks was still significant ($F_{(1,153)}$ =9.473, p<.005) explaining slightly less variance (5.8 %) in athlete achievement rank.

Participant weight was therefore found to be a significant discriminator between low and high-rank sport participants as well as between high-rank sport participants and non-sport participants.

Height (cm):

It was expected that high-rank sports participants would be taller than the low-rank participants, with the non-sport participants being the shortest, due to the advantages in sport of height and the correlations found between height and rank for the team sports under investigation in previous research (Singer and Janelle, 1999). Inspection of the mean scores revealed the high-rank sport participants to indeed be the tallest, however the non-sport participants were found to be slightly taller than the low rank sport participants. With the non-sport participants included, the group differences were found to be significant ($F_{(2,196)}$=4.082, p<.05) explaining 4% of variance achievement rank. Bonferroni tests revealed the high-rank sport participants to be significantly taller than the low-rank sport participants (p<.05) but not significantly taller than the non-sport participants. The low-rank and non-sport participants did not significantly differ in height either. When the non-sport participants were excluded from the analysis, the difference in height between the two sports ranks remained significant (F(1,153) =8.365. p<.005), slightly increasing the explanatory power of participant height over achievement rank to 5.2 %.

Participant height was therefore found to be a significant discriminator between low and high-ranking sport participants but not between sport and non-sport playing participants.

Hours trained/played per week:

It should be noted that in this analysis and the one that immediately follows (years played) that inclusion of the non-sport participant group would be misleading (and thus has been omitted) because the criterion for inclusion in this group was absence of participation in sport, and hence this group automatically obtained scores of zero on 'hours trained/played per week' and 'years played'. It was expected that the high-rank sport participants would train and play more hours per week than the low-rank sport participants due to both the demands of higher sport participation and the need of regular training/playing to achieve this standard. This was found to be the case with the rank difference found to be significant ($F_{(1,153)}$= 25.948, p<.001). The effect of hours trained/played per week explained 14.5% of the variance in achievement rank. It is, of course, impossible to determine from the present data the temporal and causal ordering of time spent training/playing and sport rank (which will be discussed later in this study).

The hours a sport participant trained and played per week was found to significantly discriminate their rank (high or low).

Years played:

It was highly expected that high-rank sport participants would have played their sport for more years than the low-rank sport participants due to the increased skill acquisition and ability associated with the number of years a sport is played (Paul & Glencross, 1997). This was found to be the case ($F_{(1,153)}$= 32.151, p<.001). The effect of years played explained 17.4% of the variance in athlete achievement rank. The same caveat as indicated above applies regarding the interpretation of this relationship.

The years a sport participant spent playing their sport significantly discriminated their achievement rank (high or low).

Age:

It was expected that high-rank sport participants might be older than the low-rank participants, due to the extra years of skill acquisition and experience associated with having played a sport for longer (see above) which is in turn associated with increased age. There was no hypothesis made regarding the age of the non-sport participant group as this was considered a completely random variable. The non-sport participants were included, simply to ascertain whether they were of comparable age to the sports persons. As expected, observations of the means showed the high-rank sport participants to be older than the low-rank participants, with non-sport participants found to be the oldest. When the non-sport participants were included in the analysis, there was found to be a significant difference in age between the groups ($F_{(2,196)}$=19.698.p<.001), which accounted for 16.7% of the variance in achievement rank. Bonferroni tests indicated that the non-sport participant group were significantly older than both the high rank participants (p<.001) and the low rank participants (p<.001). The high-rank sport participants were not found to be significantly older than the low-rank participants. Not surprisingly then, when the non-sport participant group were omitted from analysis, the difference in age between the two sports ranks was no longer found to be significant (F(1,153)=2.168, n.s.).

Participants' age was found to significantly discriminate non-sport participants from both high and low-rank sport participants.

Summary of findings

Comparisons between the non-sport participants with the high & low-rank sport participants revealed the non-sport participant group to be significantly different from the high rank sport participants on only three variables (digit ratio, weight and age) and from the low rank sport participants on only one variable (age). Of these few significant differences, the age difference may be artefactual; the majority of female non-sport participants happened to be postgraduate students, making them markedly older than the sports participants who consisted almost entirely of undergraduates.

On a continuum of the athlete achievement rank, non sports-participants are far more polarised from the high-rank sport participants than from the low-rank sport participants. Hence more significant differences on variables would be expected between the non-sport participants and the high-rank sport participants than between either the non-sport participants and the low rank sport participants or between the two sports playing groups. This was not found to be the case for the latter.

The non-sport participants' mean scores fell in between the high-rank and the low-rank sport participants' mean scores for height, achievement, mental rotation and social potency. The non-sport participants were also non-significantly different from one or both of the sports rank groups (in the hypothesised direction) on: harm avoidance (compared to both low & high ranks), social potency (compared to high ranks), achievement (compared to high ranks), control (compared to both low & high ranks), mental rotation (compared to low ranks) and height (compared to high rank). This strongly indicates that the non-sport participants were not greatly heterogeneous from the team sports participants on a wide range of physiological, psychological and mental variables associated with athlete achievement rank.

If a direct comparison had been made between the non-sport participants and the overall sport participants (both ranks combined), it is expected that more of the group differences would have been found significant in their expected directions. Similar blocked comparisons have, however been performed countless times in previous research. By deciding to compare the non-sport participants with both high and low rank achievers in sport simultaneously, we are able to not only avoid possible redundant analysis which might increase type 1 errors, but also to conclude that non sport-sport participants are far less different to the sports participants than many previous researchers have assumed or indicated. This current analysis emphasises the importance of distinguishing players' achievement rank when comparing participants' variable scores and also suggests that there is still a gap between a predisposition to sporting excellence (as measured by digit ratio, mental rotation ability and personality traits) and actual achieved sporting excellence, which could be explained in terms of various environmental influences. This issue will be explored in detail later in this investigation.

As proposed in the introduction of this analysis, it has been decided to omit the non-sport participants from all further analysis. This is because there was found to be a lack of significant differences between the non-sport participants and the two different sport participant groups with regards to many of the variables. Their inclusion might therefore result in the actual obscuring of significant differences on such variables between the high and the low rank sport participants in further analysis.

With regards to comparisons between the high and low-rank sport participants, the low rank participants differed significantly from the high rank participants in the expected direction for digit ratio, social-potency, weight, height, hours trained/played and years played. All of these variables are consistently considered in research to be important discriminating factors between non-elite and elite team performers. The low rank and the high rank sport participants also differed in the expected direction, although non-significantly, for achievement and age. The only unexpected research finding that occurred was with regards to mental rotation, which was found to be significantly negatively correlated with achievement rank (when the non-sport participants were removed from analysis), being in the opposite direction to hypothesised (to be discussed later in this investigation).

With regards to the dependent variables, the two different sports participant groups were therefore, found to differ markedly more than when comparisons were made between these groups and the non-sport playing control group. It was disappointing to find no significant differences between the high and the low ranking sport participants on three out of the four personality subscales. This raises questions regarding these variables, to be addressed at a later point in this investigation.

Analysis 2: Differences in variable scores as a function of sport contact intensity and participant sex

One of the theoretical foundations of this current investigation is the effects of the prenatal sex hormones, testosterone and oestrogen, which are sexually differentiated and represented by 2D: 4D digit ratio measures. Participant sex, however in previous research has often not been accounted for with its influence not being investigated. In this current investigation participant-sex is expected to have an influence upon virtually all of the dependent variables previously investigated in the first analysis.

This second analysis will also investigate the much less researched, but nevertheless important influence of 'sport contact intensity' upon the participants' variable scores. This is to ascertain which variables discriminate between team sports participants who play at different contact intensities (low, moderate and high). Findings may also indicate which factors attract individuals to their contact-specific type of sport. Finally the interaction between sex and sport on each of the variables will be examined to ascertain if sex differences for variables vary when comparing basketball, football and rugby.

Although it is hoped that the values of the investigated variables may largely differ in relation to these distinct separate moderating categories, it is still hoped that the proposed model will apply equally across sports of varying contact intensity and participant sex. This is a preliminary analysis to see how true that is likely to be.

Participant sex is expected to have a significant influence on many of the variables. In addition to evident physiological differences such as height and weight, sex differences were anticipated with regards to digit ratio, the four different personality subscales and mental rotation ability (as predicted from previous research findings). The sex differences on these variables are proposed to be primarily due differing proportions of the prenatal sex hormones; testosterone and oestrogen among males and females (as discussed in detail previously). Significant differences were not expected between the sexes for some variables such as age, however males were expected to train more per week due to the more competitive nature of male university sport. Males were also expected to have played their sports for significantly longer due to the well-established socialisation of males into sport participation at a much earlier age within British culture (Holt, 1989).

The three sports chosen for investigation vary on the degree of contact required in a linear way: basketball being of low contact intensity, football of moderate contact intensity and rugby of high contact intensity. Previous research (as presented in introduction) suggests that high contact sport participants vary in certain personality traits from those who participate in low contact sports. I consider these differences to be largely influenced by prenatal sex hormones, as represented by 2D: 4D digit ratio. Low digit ratios thought to represent high testosterone and low oestrogen (more characteristic among males) will be expected to be more prevalent among higher contact sport participants and high digit ratios, thought to represent high oestrogen and low testosterone (more characteristic among females) are expected to be more prevalent among lower contact intensity sport participants.

Finally in this second analysis, the interaction of sex and sport will be investigated to see if there are significant sex differences between sport participants of differing contact intensities for any of the variables. It is expected that female participants in higher contact sports may be more masculinised. It will be of interest to see if sex differences diminish in sports with higher contact.

A series of two-way ANOVA's were performed to ascertain the influence of the participants' sport contact intensity (three levels) and their sex (two levels) as well as the interaction of both these independent variables on a variety of variables thought to influence athlete achievement rank (as used in the previous analysis). It should again be stressed that the non-sport participants have been excluded for this analysis.

Table 6 (overleaf) presents the means and standard deviations, while table 7 (overleaf) presents the values for inferential statistics, comparing the participants of different sex within the three different sport contact intensity categories (basketball, football, rugby) on the dependent variables. The findings are as follows:

Findings

The findings regarding the predictor variables are as follows:

Digit ratio:

It was hypothesised that male sport participants would have lower 2D: 4D digit ratios than the female sport participants. This was found to be the case ($F_{(1,149)}$ =9.142, p<.005). Participant sex accounted for 5.8 % of the variance in the participants' 2D: 4D digit ratios. It was expected that 'sport contact intensity' may be negatively correlated with 2D: 4D digit ratio, due to its considered associations with high prenatal-testosterone and low prenatal oestrogen. The expected sport rank-order for the mean 2D: 4D digit ratio scores, therefore, from lowest to highest would be: rugby-football-basketball. The actual rank order was rugby-basketball-football.

No significant differences were found for the mean 2D: 4D digit ratio scores between the different sports played ($F_{(2,149)}$=.564, ns) nor was there a significant interaction between sport contact intensity and participant sex for digit ratio ($F_{(2,149)}$ =2.444, ns). A bar chart displaying these findings is presented in figure 3 overleaf. Sports participants' 2D: 4D digit ratio was found to significantly discriminate their sex but not the contact intensity of the sport they played.

Results: Analysis 2

Table 6:
The means and standard deviations for sport and sex differences (non-sport group excluded)

Dependent variable	Basketball			Football		
Sex	Male	Female	Overall	Male	Female	Overall
Digit Ratio	M=.9610 Sd=.02258	M=.9707 Sd=.02349	M=.9662 Sd=.02334	M=.9553 Sd=.01729	M=.9773 Sd=.02776	M=.9679 Sd=.02608
Harm Avoidance	M=5.3043 Sd=3.19708	M=5.5385 Sd=2.78899	M=5.4286 Sd=2.95804	M=6.4783 Sd=2.62626	M=6.3871 Sd=2.72858	M=6.4259 Sd=2.66070
Social Potency	M=8.0870 Sd=3.38329	M=6.7692 Sd=4.21718	M=7.3878 Sd=3.86661	M=8.9565 Sd=3.28188	M=7.6774 Sd=4.53422	M=8.2222 Sd=4.06395
Achievement	M=7.5652 Sd=3.14536	M=8.0000 Sd=2.81425	M=7.7959 Sd=2.95084	M=6.7826 Sd=3.24677	M=7.0000 Sd=3.33667	M=6.9074 Sd=3.26946
Control	M=6.8696 Sd=3.30708	M=8.0385 Sd=3.34043	M=7.4898 Sd=3.34242	M=6.5217 Sd=4.23051	M=7.1290 Sd=4.27973	M=6.8704 Sd=4.22948
Mental Rotation	M=13.2609 Sd=3.73214	M=10.8462 Sd=2.92154	M=11.9796 Sd=3.50886	M=11.2609 Sd=3.20819	M=11.1613 Sd=3.72466	M=11.2037 Sd=11.2037
Parental Ethnicity %	Cauc=73.9% Non=26.1%	Cauc=92.3% Non=7.7%	Cauc=83.7% Non=16.3%	Cauc=100 % Non=0%	Cauc=96.8% Non=3.2%	Cauc=98.1% Non=1.9%
Weight (KG)	M=73.1304 Sd=8.68805	M=64.3462 Sd=10.46114	M=68.4694 Sd=10.54574	M=74.0435 Sd=6.72498	M=62.7097 Sd=7.81534	M=67.5370 Sd=9.23838
Height (cm)	M=182.7435 Sd=7.36823	M=169.1423 Sd=7.83720	M=175.5265 Sd=10.19354	M=180.8826 Sd=6.58557	M=165.3806 Sd=7.72539	M=171.9833 Sd=10.56657
Hours trained/played	M=1.9130 Sd=.99604	M=2.3462 Sd=1.19808	M=2.1429 Sd=1.11803	M=2.3913 Sd=1.19617	M=2.2258 Sd=.84497	M=2.2963 Sd=1.00244
Years played	M=7.8478 Sd=3.97559	M=5.6385 Sd=4.98583	M=6.6755 Sd=4.62950	M=13.4348 Sd=2.29280	M=6.1194 Sd=4.11278	M=9.2352 Sd=5.00887
Age	M=20.4348 Sd=1.67403	M=20.1923 Sd=1.35703	M=20.3061 Sd=1.50283	M=20.4783 Sd=1.56291	M=20.2903 Sd=1.32145	M=20.3704 Sd=1.41816

Table 6 (continued)

Dependent Variable	Rugby			Males	Females
Sex	**Male**	**Female**	**Overall**	**Overall**	**Overall**
Digit Ratio	M=.9609 Sd=.02290	M=.9630 Sd=.02149	M=.9619 Sd=0.2204	M=.9592 Sd=.02106	M=.9709 Sd=.02504
Harm Avoidance	M=5.4815 Sd=2.87389	M=4.8000 Sd=3.59398	M=5.1538 Sd=3.22603	M=5.7397 Sd=2.91084	M=5.6341 Sd=3.06921
Social Potency	M=8.8148 Sd=3.34016	M=7.1600 Sd=4.20991	M=8.0192 Sd=3.83733	M=8.6301 Sd=3.31037	M=7.2317 Sd=4.30130
Achievement	M=6.5185 Sd=3.21499	M=7.7600 Sd=2.75802	M=7.1154 Sd=3.03996	M=6.9315 Sd=3.18995	M=7.5488 Sd=3.00268
Control	M=6.8889 Sd=3.88620	M=7.6400 Sd=3.79561	M=7.2500 Sd=3.82394	M=6.7671 Sd=3.78051	M=7.5732 Sd=3.82658
Mental Rotation	M=12.0370 Sd=3.67404	M=11.4800 Sd=4.45459	M=11.7692 Sd=4.03716	M=12.1781 Sd=3.59530	M=11.1585 Sd=3.70342
Parental Ethnicity %	Cauc=100 % Non=0%	Cauc=100 % Non=0%	Cauc=100% Non=0%	Cauc=91.8 % Non=8.2%	Cauc=96.3 % Non= 3.7%
Weight (KG)	M=84.4074 Sd=13.70923	M=68.2800 Sd=10.93359	M=76.6538 Sd=14.77396	M=77.5890 Sd=11.51308	M=64.9268 Sd=9.86299
Height (cm)	M=181.7926 Sd=5.60542	M=170.1160 Sd=5.88789	M=176.1788 Sd=8.18749	M=181.8055 Sd=6.46067	M=168.0171 Sd=7.46724
Hours trained/played	M=2.8889 Sd=1.28103	M=3.1200 Sd=.88129	M=3.0000 Sd=1.10258	M=2.4247 Sd=1.22381	M=2.5366 Sd=1.04462
Years played	M=9.2778 Sd=4.78847	M=2.4400 Sd=1.57480	M=5.9904 Sd=4.97564	M=10.1370 Sd=4.48784	M=4.8451 Sd=4.15702
Age	M=20.2963 Sd=1.10296	M=20.6400 Sd=.90738 **Table 7:**	M=20.4615 Sd=1.01868	M=20.3973 Sd=1.43120	M=20.3659 Sd=1.22235

Table 7:
The values for inferential statistics for sex and sport differences

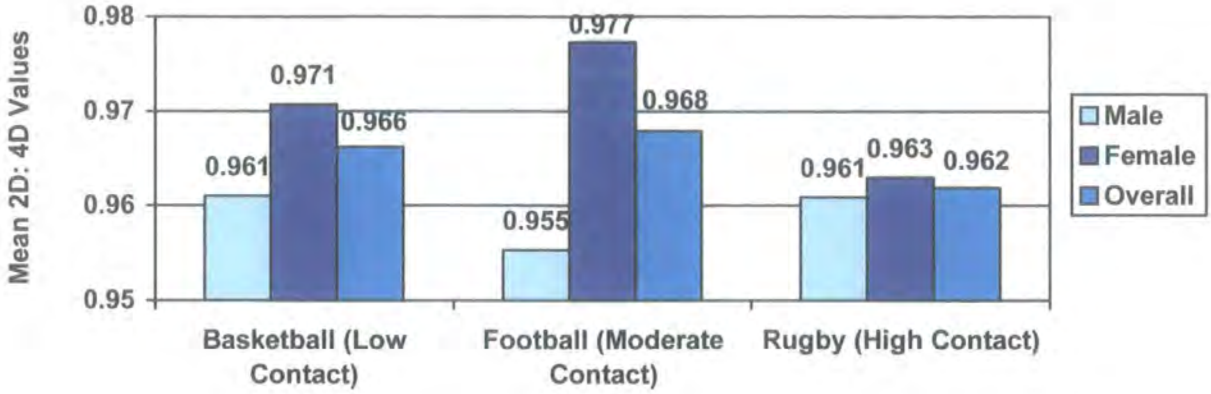
Dependent variable	*F* sex	Eta^2sex	Direction of effect for significant relationships
Digit ratio	$F(1,149)=9.142.\ p<.005$	.058	Males sig lower than females
Harm Avoidance	$F(1,149)=.140$ (ns)	.001	N/A
Social Potency	$F(1,149)=5.065.\ p<.05$	.033	Males sig higher than females
Achievement	$F(1,149)=1.589$ (ns)	.011	N/A
Control	$F(1,149)=1.842$ (ns)	.012	N/A
Mental Rotation	$F(1,149)=3.010$ (ns)	.020	N/A
Parental Ethnicity	$X^2\ (1)=1.469$ (ns)	.00940	N/A
Weight (Kg)	$F(1,149)=55.675.\ p<.001$	.272	Males sig heavier than females
Height (cm)	$F(1,149)=148.199.\ p<.001$	.499	Males sig taller than females
Hours trained/played	$F(1,149)=.918$ (ns)	.006	N/A
Years played	$F(1,149)=75.607.\ p<.001$	.337	Males sig higher than females
Age	$F(1,149)=.018$ (ns)	.000	N/A

Dependent Variable	*F* sport	Eta^2 sport	Direction of effect for significant relationships
Digit ratio	$F(2,149)=.564$ (ns)	.008	N/A
Harm Avoidance	$F(2,149)=2.727$ (ns)	.035	N/A
Social Potency	$F(2,149)=.670$ (ns)	.009	N/A
Achievement	$F(2,149)=1.106$ (ns)	.015	N/A
Control	$F(2,149)=.361$ (ns)	.005	N/A
Mental Rotation	$F(2,149)=.700$ (ns)	.009	N/A
Parental Ethnicity	$X^2\ (1)=14.665.\ p<.005$	.07784	[redacted]
Weight (Kg)	$F(2,149)=10.398.\ p<.001$	.122	B-ball players sig less than rugby players ($p<.005$) Ftball players sig less than rugby players ($p<.001$)
Height (cm)	$F(2,149)=2.876$ (ns)	.037	N/A
Hours trained/played	$F(2,149)=9.456.\ p<.001$	.113	B-ball players sig less than rugby players ($p<.001$) Ftball players sig less than rugby players ($p<.005$)
Years played	$F(2,149)=14.636.\ p<.001$	.164	B-ball players sig less than ftball players ($p<.001$) Rugby players sig less than ftball players ($p<.005$)
Age	$F(2,149)=.170$ (ns)	.002	N/A

Table 7 (Continued):

Dependent Variable	*F* Interaction	Interaction Eta²
Digit ratio	*F*(2,149)=2.444(ns)	.032
Harm Avoidance	*F*(2,149)=.308 (ns)	.004
Social Potency	*F*(2,149)=.036 (ns)	.000
Achievement	*F*(2,149)=.393 (ns)	.005
Control	*F*(2,149)=.072 (ns)	.001
Mental Rotation	*F*(2,149)=1.411 (ns)	.019
Parental Ethnicity	[redacted]	[redacted]
Weight (Kg)	*F*(2,149)=1.753 (ns)	.023
Height (cm)	*F*(2,149)=1.002 (ns)	.013
Hours trained/played	*F*(2,149)=1.029 (ns)	.014
Years played	*F*(2,149)=6.590. *p*<.005	.081
Age	*F*(2,149)=.756 (ns)	.010

Figure 3
Bar chart comparing mean 2D:4D values of different sport contact intensity groups and sex differences between and within these sports groups



Harm Avoidance:

It was hypothesised that male sports participants would score lower on the MPQ subscale of harm avoidance than the female sports participants. This was not found to be the case ($F_{(1,149)}$=.140, ns). It was hypothesised that sport contact intensity would be negatively correlated with 'harm-avoidance'. As a result the expected rank-order of participants' mean scores for harm avoidance from highest to lowest would be: basketball-football-rugby. The actual rank order was: football-basketball-rugby. The differences between the mean group scores on this variable were not found to be significant ($F_{(2,149)}$=2.727, ns). No significant interaction effect was found between the participants' sex and their sport contact intensity for harm-avoidance ($F_{(2,149)}$=.308, ns).

The 'harm-avoidance' scores of sports participants' did not significantly discriminate their sex or the contact intensity of the sport they played.

Social Potency:

It was hypothesised that male participants would score higher on the MPQ subscale of social potency than female sports participants. This was found to be the case ($F_{(1,149)}$

=5.065.p<.05). The participants' sex accounted for 3.3 % of the variance in their social potency scores. No prediction was made with regards to a relationship between sport contact intensity and the participants' scores on social potency. The sport rank-order of mean scores on this variable, from highest to lowest was: football-rugby-basketball. The differences between the different sports' mean scores in this direction for this personality variable were not significant ($F_{(2,149)}$=.670, ns). No significant interaction effect was found between the participants' sex and their sport contact intensity for social potency either ($F_{(2,149)}$=.036, ns).

Social-potency was found to discriminate sports participants' sex but not the contact intensity of the sport they played.

Achievement:

It was hypothesised that male sport participants would have higher scores than female sport participants on the MPQ subscale of Achievement. This was not found to be the case ($F_{(1,149)}$=1.589, ns). No prediction was made regarding sport contact intensity and achievement. The rank order of mean scores for the different sports from highest to lowest on this variable were as follows: basketball-rugby-football. The differences between the mean scores for the different sports in this direction were not found to be significant ($F_{(2,149)}$=1.106, ns). No significant interaction effect was found between the participants' sex and their sport contact intensity for achievement. ($F_{(2,149)}$=393, ns).

Sports participants' scores on 'achievement' were not found to discriminate their sex or the contact intensity of the sport they played.

Control:

It was hypothesised that male sport participants would have lower scores than female sport participants on the MPQ subscale of control. A sex difference occurred in this direction, however it was not found to be significant ($F_{(1,149)}$=1.842,ns). It was hypothesised that sport contact intensity would be negatively correlated mean 'control' scores, therefore the predicted rank-order of mean scores for the different sports from highest to lowest was: basketball-football-rugby. This was not found to be the case, as the actual rank order was: basketball-rugby-football. The difference between the mean scores of the different sports in this direction was not significant $F_{(2,149)}$=.361 (ns). No significant interaction effect was found between the participants' sex and their sport contact intensity for the personality variable: control ($F_{(2,149)}$=.072, n.s.).

Sports participants' mean scores for control were not found to discriminate their sex or the contact intensity of the sport they played.

Mental Rotation:

It was hypothesised that male sports participants would score higher than female sports participants on the mental rotation task. A sex difference occurred in this direction, however it was not found to be significant ($F_{(1,149)}$=3.010, n.s). No prediction was made regarding a relationship between sport contact intensity and mental rotation. The rank-order of mean scores for the different sports from highest to lowest, were as follows: basketball-rugby-football. The difference in mean mental rotation scores between the different sports in this direction was not significant ($F_{(2,149)}$=.700, n.s). No significant interaction effect was found between the participants' sex and their sport contact intensity for mental rotation ($F_{(2,149)}$=1.411 , n.s).

Mental rotation was not found to be a significant discriminator of the sports participants' sex or the contact intensity of the sport they played.

The findings regarding the secondary variables are as follows:

Parental Ethnicity:

No hypotheses were made regarding participant sex and sport contact intensity with regards to the sports participants' parental ethnicity. There were more non-Caucasian male participants (8.2 %) compared to non-Caucasian female participants (3.7 %) but this difference was not significant (X^2 (1)=1.469,ns). Regarding sport contact intensity, the rank-order of the percentage of participants who were not of exclusively Caucasian decent (non-Caucasian) were from highest to lowest, as follows: basketball-football-rugby. The difference between the different sports in this direction was found to be significant (X^2 (1)=14.665,p<.005). Sport contact intensity accounted for 7.8 % of the variance in ethnicity. It was not possible to examine interaction effects as the cell sizes for the non-Caucasian groups were lower than five and thus of invalid size.

The parental ethnicity of sports participants was found to significantly discriminate the contact intensity of the sports they play but not their sex.

Weight:

It was expected that male sports participants would weigh more than female sports participants. This was found to be the case ($F_{(1,149)}$ =55.675, p<.001). Sport participant sex accounted for 27.2 % of variance in their weight. From observing the individual physical requirements of the three sports, it was expected that rugby players would be the heaviest followed by basketball players and finally football players would be the lightest. This was found to be the case. The differences in mean weight between the different sport groups in this direction were found to be significant ($F_{(2,149)}$=10.398.p<.001). Sport contact intensity accounted for 12.2 % of the variance in the participants' weight. Bonferroni post-hoc tests revealed that the rugby players were significantly heavier than both the basketball players (p<.005) and the football players (p<.001), but the football players were not found to be significantly different from the basketball players. No significant interaction effect was found between the sport participants' sex and their sport contact intensity with regards to their weight ($F_{(2,149)}$ =1.753, ns).

Sports participant's weight was found to significantly discriminate both their sex as well the contact intensity of the sports they participated in.

Height (cm):

It was expected that male sport participants would be taller than female sports participants. This was found to be the case ($F_{(1,149)}$=148.199.p<.001). Participant sex accounted for 49.9 % of the variance in the participants' height. It was expected that basketball players would be the tallest of the three sports followed by rugby players, with football players being the shortest. This prediction was made from the individual physical requirements of the three sports. This was not found to be the case as the actual rank-order of height for the different sport groups, from tallest to shortest was: rugby-basketball-football. The differences in height between the different sports groups in this direction were not found to be significant ($F_{(2,149)}$=2.876, ns). No significant interaction effect was found between the participants' sex and their sport contact intensity for their height either ($F_{(2,149)}$=1.002, ns).

Sport participants' height was found to significantly discriminate their sex but not the contact intensity of the sports they played.

Hours trained/played per week:

It was expected that male sport participants might train and play more per week than female sports participants due to the observed increased competitiveness of male university sport. This was not found to be the case with the sex difference found not to be significant ($F_{(1,149)}$=.918, ns). No prediction was made regarding the relationship between sport contact intensity and 'hours trained/played per week'. The rank-order of the mean scores for the different sport groups from highest to lowest, was as follows: rugby-football-basketball. The differences between the mean scores for the different sport groups in this direction was found to be significant ($F_{(2,149)}$=9.456.p<.001). Sport contact intensity accounted for 11.3 % of the variance in 'hours trained/played per week'. Bonferroni post-hoc tests revealed that rugby players trained/played significantly more than both the basketball players (p<.001) and football players p<.005). There was, however, no significant difference between the football and basketball players. No significant interaction effect was found between the participants' sex and their sport contact intensity with regards to this dependent variable ($F_{(2,149)}$=1.029, ns).

The 'hours trained/played per week' by a sports participant was found to significantly discriminate the contact intensity of the sport they played but not their sex.

Years played:

It was expected that male sports participants might have played their sport for more years than their female counter-parts due to the acknowledged earlier socialisation of males into sport within British culture (Holt, 1989). This was found to be the case

($F_{(1,149)}$=75.607.p<.001). Participant sex accounted for 33.7 % of the variance in the number of years they had played their sports. No prediction was made regarding a relationship between sport contact intensity and years played. The rank-order of mean scores for the different sport groups, from highest to lowest, was as follows: football-basketball-rugby. The differences in mean scores between the different sport groups were found to be significant ($F_{(2,149)}$=14.636.p<.001). Sport contact intensity accounted for 16.4 % of the variance in years played. Bonferroni post-hoc tests revealed that football players had played for significantly more years than both the basketball players (p<.001) and the rugby players (p<.005). There was, however no significant difference between rugby and basketball players with regards to years played. A significant interaction effect was found between the participants' sex and their sport contact intensity with regards to years played ($F_{(2,149)}$=6.590.p<.005). This interaction effect accounted for 8.1 % of the variance in years played. From observing the relevant mean scores, it was revealed that both the male football and male rugby players had played for markedly more years than the female football and female rugby players in comparison to the same trend found among the basketball players.

The years the sports participants had played their sport was found to be a significant discriminator of the contact intensity of the sport they played and their sex (particularly among football and rugby players).

Age:

No prediction was made with regards to a correlation between the sports participants' age and their sex. Male sports participants were found to be slightly older than the female sports participants, but the age differences were not found to be significant ($F_{(1,149)}$=.018, ns). No prediction was made regarding a relationship between sport contact intensity and participant age. The rank-order of mean ages for the different sport groups, from oldest to youngest, was as follows: rugby-football-basketball. The differences between the different sport groups in this direction, was not found to be significant ($F_{(2,149)}$=.170, ns). No significant interaction effect was found between the participants' sex and their sport with regards to their age ($F_{(2,149)}$=.756, ns).

Summary

The male sports participants were found to be significantly different from the female sports participants in the hypothesised direction on the variables of digit ratio, social potency, weight, height, and years played and non-significantly in the expected direction for control and mental-rotation. As with the first analysis, only one of the four personality variables (social-potency) was found to show a significant sex difference. However the fact that digit ratio was found to be sexually dimorphic, suggests a significant sex difference in the prenatal sex hormones, with males having higher prenatal testosterone and lower prenatal oestrogen than females. The other three personality variables, as well as mental rotation, have also previously been considered to be sexually dimorphic because of research evidence which also links them with these sex hormones. As 2D: 4D did show a significant sex difference, these personality traits are either expressed independently of digit ratio or the validity of these four measures is questionable (this will be considered later in the investigation).

The second major aim of this analysis was to investigate the influence of the contact intensity of the three different sports played upon the participants' scores on the dependent variables. The findings were disappointing. The only variables that were found to be significantly different between the three sports were: parental ethnicity, weight, hours trained/played per week and years played. All these variables were 'secondary variables', as they were considered to be correlates rather than the major causes of athlete achievement rank and consequently were not included in the proposed model. It was also expected that sex differences between the dependent variables would diminish as the sport contact intensity increased with the female sports participants adopting more masculinized characteristics. Observation of the findings revealed this not to be apparent. As a result, this second analysis demonstrates sport contact intensity as a moderating variable to have far less of an influence on the dependent variables (and in particular the predictor variables) in comparison to participant sex as a moderating variable for the sport participants investigated.

No significant differences between sports were found for any of the personality variables, despite the fact that the variable harm-avoidance had been considered to be quintessentially related (negatively) to sport contact intensity in previous research. This again either raises questions regarding the validity of the personality variables used or indicates that the personality variables are expressed independently of sport contact intensity.

It should be noted that a potential explanation exists for why the rugby players were found to have played their sport for significantly less time than football players. It rests on the sex composition of the sample and the sex specific opportunities for the two sports. There is a greater opportunity for women to play organised football rather than rugby at a younger age. Many women do not get the opportunity to play rugby competitively until they reach university, due to a lack of resource availability, such as coaches and pitches. For male rugby participants however, youth playing opportunities are far more abundant. As a consequence, the combined sex mean for the rugby players was significantly lower than that for the football players. Interestingly, and possibly related to this, the only one significant interaction that was found between sex and sport for all of the variables, was regarding 'years played sport'. This may be the result of a historical trend in British culture for males to be socialised to participate in recreational/organised sport at a much earlier age than females in nearly all sports (Holt, 89).

Analysis 3: Inter-correlation matrix of all variables

The purpose of this analysis was to gain an overview of all the significant correlations that occurred between all of the variables used in this study. There were four categories of variables: 1) predictor variables: the main predicted influencing variables on the outcome variable of athlete achievement rank included in the model, 2) secondary variables: these are variables not included in the model but which were measured so that their influence upon athlete achievement rank could be monitored and accounted for, 3) moderating variables: these are the variables of participant sex and sport contact intensity, considered to moderate both the predictor and the secondary variables' correlations with rank. 4) The fourth and final category is the outcome variable, which is athlete achievement rank.

In this analysis, zero-order correlations were computed between all the variables in the investigation. In addition to examining predicted relationships between predictor, secondary and moderating variables with the outcome variable of athlete achievement rank, a second aim was to examine relationships that may be of interest among all the variables. This analysis will also be importantly used to investigate co-linearity between any of the variables. Where two items are highly correlated (approaching 1.00), they may effectively be measuring the same thing and inclusion of both violates the requirements of multiple regression (to be performed in the next analysis). Consequently some variables may need to be removed after this current investigation.

Bivariate correlations were computed using the Pearson's product-moment correlation coefficient. The Pearson's is a parametric test that uses interval level data, consequently, the parental ethnicity variable was excluded from analysis as it was a categorical variable.

The moderating variables sport contact intensity and participant sex were, for the purpose of this third analysis categorised as predictor variables. The data from the non-sport participant group were completely omitted from the current analysis, in line with the conclusions from the results of the earlier analyses. Because of the overlap in scores between the control and sports groups, their inclusion would depress many of the correlations within the matrix causing at least some potentially important correlations to appear non-significant. As with any bivariate correlation, causality between two variables cannot be assumed because there may be other measured or unmeasured variables affecting the results (the 'third variable problem'). Also the possible direction of causality between any two variables remains unknown (except where a fixed variable such as sex is considered).

In interpreting the intercorrelation matrix of all the variables (Table 8 overleaf), I will examine in turn:

1. Correlations among the secondary variables.
2. Correlations between the secondary variables and the predictor variables.
3. Correlations among the predictor variables (including moderator variables).

4. Correlations between the outcome variable (athlete achievement rank) and the secondary variables.
5. Correlations between the outcome variable and the predictor variables (including moderator variables).

Findings

Correlations among secondary influencing variables

Age correlated positively with weight ($r=.216$, $p<.01$), and years played ($r=.306$, $p<.001$). Height also correlated positively with weight ($r=.643$, $p<.001$) and years played ($r=.368$, $p<.001$). Weight correlated positively with years played ($r=.332$, $p<.001$) and hours trained/played per week ($r=.195$, $p<.05$). Surprisingly no association was found between years played and hours spent training/playing per week.

Height was found to be correlated with years played. It may be that taller individuals receive early encouragement to pursue sport, especially where height is an important component of success (e.g. basketball). This suggestion is given further support by the fact that height was also positively correlated with athlete achievement rank.

Unexpectedly weight was found to be correlated with age, years played and hours trained/played per week. The common factor among these variables associated with weight is that they are all time duration variables. The more time an individual spends training and playing their sport (with older people having a greater likelihood of having played their sport for longer), the more their bodies will develop physically and respond to the sport-specific nature of training (e.g. weight training for mass and strength in rugby and body fat percentage reduction and lean tissue increases to improve speed and

Results: Analysis 3

Table 8:

Inter-correlation matrix of all variables

(non-sport group excluded)

Variables	Age	Height	Weight	Sport	Years	Hours	Men Rot	Dig Rat	Rank	Harm av	Control	Soc Pot	Achieve
Sex	.012	.703****	.512****	.041	.524****	-.050	.139	-.245***	.141	.018	-.106	.179*	-.100
age		.148	.216**	.048	.306****	.132	-.054	-.054	.104	-.075	.057	.067	.138
Height			.643****	.030	.368****	.015	.093	-.251***	.196*	.043	-.002	.149	.021
Weight				.271***	.332****	.195*	.048	-.149	.244***	.060	-.021	.145	-.072
Sport					-.060	.309****	-.022	-.074	.136	-.040	-.024	.064	-.087
Years						.115	-.080	-.218**	.349****	.081	.013	.237***	-.048
Hours							-.142	-.139	.421****	-.062	.032	.238***	.192*
Men Rot								.026	-.164*	-.043	.085	.067	.168*
Dig Rat									-.353****	-.040	-.051	-.172*	-.117
Rank										.064	.022	.226**	.025
Harm Av											.296****	-.186*	.092
Control												-.330****	.368****
Soc Pot													.093

Key

****= $p<.001$

***= $p<.005$

**= $p<.01$

*= $p<.05$

agility in football). As a result those who are older, have played for more years, or who train/play more hours per week would be expected to have an increase in their body weight associated with this fat reduction and increased lean muscle mass.

Correlations between the predictor variables and the secondary variables.

Sex was treated as a dummy variable with male participants coded as 1 and female participants as 0. As would be expected sex correlated positively with height (r=.703, p<.001), weight (r=.512, p<.001) and years played (r=.524, p<.001), indicating that male sports participants were taller, heavier and started playing earlier than their female contempories. Sport was coded with the highest intensity sports scored as the highest. Sport contact intensity was correlated positively with weight (r=.271, p<.005) and hours trained/played per week (r=.309, p<.001). Mental rotation did not correlate significantly with any of the secondary variables. Digit ratio correlated negatively with height (r=-.251, p<.005) and years played (r=-.218, p<.01). Neither harm avoidance or control correlated with any of the secondary variables. Social potency correlated positively with years played (r=.237, p<.005) and hours trained/played per week (r=.238, p<.005). Achievement correlated positively with hours trained (r=.192, p<.05).

Height was found to be negatively correlated with digit ratio, suggesting that individuals with more prenatal testosterone (and less prenatal oestrogen) are taller. This finding is not unexpected, as it is documented that a primary influence upon males greater height relative to females is the testosterone receptors in the bones responding to greater amounts of prenatal testosterone (Marcus, Leary, Schneider, Shane, Favus, and Quigley, 2000; Tanner, 1990). This is further supported by the fact that male participants were found to be significantly taller in this analysis.

Years played was negatively correlated with digit ratio and positively correlated with social potency (as well as rank). Perhaps individuals who are physiologically predisposed to sporting excellence (as indexed by low digit ratios) are intrinsically motivated or encouraged by others, due to their talent, to start playing competitive sports at an earlier age, which in turn makes them more likely to reach a higher level of sporting excellence (as indicated by the significant correlation with rank). The dominance, assertiveness and extroversion subsumed by the personality subscale of social potency may be associated with finding the prospect of team sport participation more congenial at an earlier age.

Hours trained/played per week was unexpectedly correlated with sport contact intensity, as well as with the two personality subscales of social-potency and achievement. An explanation for the correlation with contact intensity is that the three sports investigated are played at very different competitive levels at university. University rugby is the most competitively played team sport in British universities and is often the route to professional or international participation. University football is less competitively played as talented players will already be contracted professionally well before university age. Football is still however the sport that is most widely participated in, in this country. Basketball is by far the least competitive of the three sports, as it is considered a minority sport within Britain and British universities, with consequently much smaller participant bases. From the table of means in the first analysis, it can be seen that the competitive level of the three sports is highly positively related to the hours spent training/playing per week. Rugby players train the most followed by football players with the basketball players training the least. This correlation therefore appears to be in no way associated with the contact intensities of the three sports investigated but rather their relative competitiveness. A possible explanation for why hours trained/played per week was positively correlated with the personality variables of achievement and social potency may be that assertive or dominant people are more determined to achieve in their sport and they are therefore more prepared to put the extra hours of training and playing in, necessary to attain that achievement. This proposed explanation is supported by the finding that hours trained was also positively correlated with athlete achievement rank.

Correlations among the predictor variables

Participant sex was correlated negatively with digit ratio ($r=-.245, p<.005$) and positively with social potency ($r=.179, p<.05$). Sport contact intensity did not significantly correlate with any of the other predictor variables. Mental rotation correlated with achievement ($r=.168$, $p<.05$). Digit ratio negatively correlated with social potency ($r=-.172$, $p<.05$). Harm Avoidance positively correlated with control ($r=.296$, $p<.001$) and negatively correlated with social potency ($r=-.186$, $p<.05$). Control positively correlated with achievement ($r=.368$, $p<.001$) as well as being negatively correlated with social potency ($r=-.330$, $p<.001$). From the correlations among the predictor variables (with moderating variables included also) it can be concluded that none of the predictor variables are in danger of co-linearity.

There were some expected correlations that failed to occur. Participant sex was expected to be positively correlated with mental rotation scores (with male participants expected to score higher), especially as participant sex was found to be negatively correlated with digit ratio, suggesting the occurrence of the sex differences in prenatal sex hormone concentrations that are thought to directly influence both digit ratio and mental rotation ability. No explanations at present can be proposed as to why this correlation did not occur. Participant sex was also expected to be correlated with all four of the personality variables, however this was only found to be the case with social-potency. This again represents the predictive failure of the other three personality variables; achievement, harm-avoidance and control. They failed to correlate not only with participant sex, but also showed no correlation with sport contact intensity and athlete achievement rank, as demonstrated in this and the previous two analyses. Interestingly, a number of expected significant correlations occurred among the personality variables (see above). This indicates that the personality variables incorporated, may indeed be valid measures, suggesting that their failure of predictive success may be due, either to an independence from the associations attributed to them by this investigation or the likelihood that these personality variables were drawn from an inventory that measures very generalised tendencies and thus had poor cross situational transfer within the specific sporting context of this investigation (with the exception of social potency). Mental rotation was unexpectedly found to be positively correlated with the personality variable of achievement. The association may be an artefact of an increased effort to perform well on the timed mental rotation task (to achieve higher scores) among those with higher achievement motivation. Mental rotation was expected to correlate negatively with digit ratio. It is possible that the mental rotation test used had a poor construct validity for measuring the specific mental rotation ability associated with successful team sport performance (to be further discussed).

Correlations between the outcome variable (athlete achievement rank) and the secondary variables

Athlete achievement Rank correlated positively and significantly with height ($r=.196$, $p<.05$), weight ($r=.244$, $p<.005$), years played ($r=.349$, $p<.001$), and hours trained/played per week ($r=.421$, $p<.001$).

All of the previous mentioned correlations were as expected. Athlete achievement rank was expected to be positively correlated with age. This did not occur, possibly due to the fact that participant age was deliberately taken from a truncated range of age eighteen to twenty-five, which may have caused a significant reduction in variance and reduced the likelihood of finding a significant correlation.

Correlations between the outcome variable and the predictor variables

Athlete achievement Rank negatively correlated with mental rotation ($r=-.164$, $p<.05$) and digit ratio($r=-.353$, $p<.001$) and correlated positively with social potency ($r=.226$, $p<.01$).

These correlations that occurred were largely as expected, except that rank was negatively correlated with mental rotation, which is contrary to hypothesised. This finding will be addressed in the discussion. Athlete achievement rank was expected to correlate with the achievement personality variable but did not. The absence of this correlation may reflect no more than the associative failure of the personality scales as a whole, or it may suggest that some individuals attain a high sport achievement rank, not because they are more achievement orientated but due to the influence of other variables such as a genetic predisposition to sporting success or due to being successfully coached.

While this analysis was extremely useful for investigating correlations between and among the different classes of variables associated with athlete achievement rank, it however, consisted solely of zero-order correlations, which provide no information on the joint impact upon rank of all these variables when common variance is partialed out.

The next logical step in analysis, is therefore to be perform multiple regressions in order to ascertain the individual influences of the predictor variables on athlete achievement rank, when the effect of all other variables are removed and also to investigate the extent to which the relationship between digit ratio (the primary predictor variable) and rank is mediated by the influence of the other predictor variables as well as the secondary variables.

Analysis 4: Multiple regressions on the dependent variables' effects on athlete achievement rank

In this analysis, 2D: 4D digit ratio will be regarded as independent of the predictor variables. As central to this analysis is the extent to which the correlation between digit ratio and achievement rank can be explained by the mediating effects of the predictor variables: mental rotation ability and the four personality variables as well as by the effects of the secondary variables.

Although previous analyses in this study have identified the correlation between mental rotation and athlete achievement rank to be significantly negative and therefore in the opposite direction to hypothesized, as a predictor variable in the proposed model, mental rotation will still be included in this fourth analysis.

Rationale for and information about multiple regression

To test the proposed model of the influences of predictor variables on athlete achievement rank, multiple regressions on the full sport participant sample were used. Predictor variables (excluding digit ratio) were entered in a stepwise fashion followed by 2D: 4D digit ratio in the second block. The aim was to determine the extent to which the zero-order association between 2D: 4D digit ratio and athletic achievement rank was reduced when mediator variables (the other predictor variables) were allowed to enter first. The resultant model was then later applied, using again stepwise and hierarchical entry, to both sexes and each type of sport contact intensity to examine whether the predictive accuracy of the model varied among these subgroups.

It should be noted that in regards to predictive ability, stepwise regression may have a tendency to cause variables to 'over fit' the data, resulting in an overestimation of their contribution as a result of chance associations. Also when investigating sub-categories of participants, the fit of the predictor variables will be likely to be diminished because of the reduced participant numbers.

A multiple regression is a statistical technique by which the independent contribution made by each candidate variable to the outcome variable is calculated. A stepwise entry method was chosen over other entry methods because it is much better suited if you have a number of candidate variables without knowing their hierarchical importance of influence. By entering the candidate variables simultaneously the stepwise method will prioritise their importance of influence for you, while automatically omitting those variables that did not have a significant influence. The aim of this analysis was to establish the relative power of the predictor variables in explaining the outcome variable (athlete achievement rank) in descending order of explanatory power with non-significant variables being excluded. The strongest correlate of the outcome variable will be automatically identified and all the other variables will be re-scaled to eliminate their statistical association with that variable. The next strongest correlate will then be selected and the two variables combine to generate a multiple regression co-efficient. All of the variables will then be rescaled to eliminate their correlation with the coefficient and so the process goes on until a score is available for all of the significant influencing predictor variables. At this stage the correlation of each variable with rank will be completely independent of its correlation with the other variables. The multiple regressions co-efficient is a measure of how well the chosen set of predictor variables predict athlete achievement rank and the calculations also show how much each measure independently contributes to the prediction.

Table 9:
A stepwise multiple regression on the effects of all the predictor variables on athlete achievement rank

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	Zero-Order	Part
1	(Constant)	4.417	.308		14.354	.000		
	Social potency	.100	.035	.226	2.863	.005	.226	.226
2	(Constant)	5.365	.510		10.516	.000		
	Social potency	.105	.035	.238	3.052	.003	.226	.237
	Mental rotation	-8.509E-02	.037	-.180	-2.312	.022	-.164	-.180
3	(Constant)	27.793	5.305		5.239	.000		
	Social potency	8.082E-02	.033	.182	2.429	.016	.226	.179
	Mental rotation	-7.940E-02	.035	-.168	-2.273	.024	-.164	-.167
	Digit ratio	-23.101	5.442	-.318	-4.245	.000	-.353	-.313

Results

The simple regression coefficient of 2D: 4D digit ratio into athlete achievement rank was first computed. This was found to be r=-.353. A stepwise regression was then specified and entered with all the predictor variables (except digit ratio) entered in the first block and with 2D: 4D digit ratio entered alone in the second block. If the correlation between digit ratio and rank was indeed completely explained by the other predictor variables, then digit ratio would have not entered the regression equation since all its variance would have been shared with the mediating variables and thus it would have added no further explanatory power.

Of the five candidate predictor variables entered into the first block of the multiple regression (mental rotation, social potency, achievement, harm avoidance and control), three of the personality variables (achievement, harm avoidance and control) failed to achieve the criteria for entry into the regression equation. This confirmed earlier analysis in this study of these data. The three variables that were found to be significantly associated with rank were digit ratio, mental rotation and social potency.

From Table 9 (above), it can be seen that the zero-order or simple correlation coefficient (r) between achievement rank and digit ratio is -.353, which when squared (r^2) reveals that 12.46% of the variance in athlete achievement rank was accounted for by the participants' digit ratios. When digit ratio was entered in the second block, the semi-partial or part correlation (sr) between rank and digit ratio was -.313 which when squared (sr^2) revealed that 9.8% of achievement rank was accounted for by digit ratio after all the variance shared with the other predictor variables was removed. The difference therefore between the two squared correlations (R^2-SR^2) was 2.66%. This revealed that only 2.66% of the relationship between participants' 2D: 4D digit ratio and their achievement rank was explained by the influence of the predictor variables social potency and mental rotation.

These findings suggest that the correlation between digit ratio and athlete rank is to a large degree independent of the influences of the other predictor variables used in this study. It was found in the previous analysis (inter-correlation matrix) that a number of secondary variables were correlated with achievement rank, in particular years played and hours trained/played per week. A major acid test of digit ratios power over rank, would therefore be to perform a second stepwise regression, but this time, with the secondary variables entered in the first block, the predictor variables (minus digit ratio) entered into the second block and digit ratio entered by itself into the third block. Digit ratio's integral importance as a primary influencing variable would be confirmed if it was still found to have a significant influence upon athlete achievement rank, when the variance of influence upon achievement rank shared with the secondary variables is removed. The afore mentioned regression (table 10) is presented below.

Table 10:
A stepwise multiple regression on the effects of all the secondary variables and the predictor variables on athlete achievement rank

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	Zero-Order	Part
1	(Constant)	3.596	.308		11.693	.000		
	Hours trained	.648	.113	.421	5. 748	.000	.421	.421
2	(Constant)	2.962	.325		9.106	.000		
	Hours trained	.594	.107	.386	5.534	.000	.421	.384
	Years played	.105	.024	.305	4.362	.000	.349	.302
3	(Constant)	20.651	4.911		4.205	.000		
	Hours trained	.550	.104	.358	5.287	.000	.421	.353
	Years played	8.728E-02	.024	.254	3.695	.000	.349	.247
	Digit ratio	-18.078	5.008	-.249	-3.610	.000	-.353	-.241

Of all the secondary variables entered into the first block of the stepwise multiple regression, only years played and hour trained/played per week were found to have significant influences upon achievement rank. Years played accounted for 6.1% of the variance in rank while hours trained/played per week accounted for 12.46% of the variance in rank, when all the variance shared with the other variables was removed. Digit ratio was still found to significantly influence achievement rank after the secondary variables were entered into the multiple regression and their associated shared variance was removed, revealing the stability of digit ratio's predictive power. The r^2 for digit ratio was 12.46%, while the sr^2 for digit ratio was 5.81%. Consequently 6.65% of digit ratio's influence upon the variance in achievement rank was due to the mediating influences of the secondary variables: hours trained/played per week and years played. This indicates that the ratio of prenatal testosterone to oestrogen as represented by digit ratio, will have some influence upon the players' initiation and intensity of sports participation, which in turn will influence their achievement rank. As suggested previously, it may be that infants demonstrating sporting potential (as related to low digit ratios) may be encouraged into participation at an earlier age or sport participation may indeed be more conducive to individuals with this biological make up. Regarding hours trained/played per week, individuals with low digit ratios are more predisposed to sporting success, making them more likely to compete in sport at a higher standard, which would result in the need to train and play more intensely and regularly per week.

The stability of the predictive model will now be investigated across the moderating variables of 'participant sex' and 'sport contact intensity' by performing a sequence of simple, stepwise and hierarchical regressions for each of these participant sub-categories.

Female sport participants:

For female sports players the simple regression of digit ratio on rank revealed the correlation to be: $r = -.325$. Calculating the r^2 revealed that 10.56% of the variance in achievement rank for female sport participants was accounted for by their 2D: 4D digit ratios, when only digit ratio was entered into the simple regression.

Table 11:
A hierarchical entry multiple regression of specific predictor variables upon athlete achievement rank for the female sport participants only

Model	Predictor Variable	B	Std. Error	Beta	T	Sig	R^2	Zero-Order	Part
1	(Constant)	4.472	.384		11.640	.000	.028		
	Social potency	6.971E-02	.046	.168	1.524	.131		.168	.168
2	(Constant)	5.029	.707		7.110	.000	.039		
	Social potency	6.961E-02	.046	.168	1.521	.132		.168	.168
	Mental rotation	-4.993E-02	.053	-.104	-.940	.350		-.104	-.104
3	(Constant)	26.354	7.548		3.491	.001	.129		
	Social potency	4.558E-02	.045	.110	1.021	.311		.168	.108
	Mental rotation	-5.219E-02	.051	-.108	-1.025	.309		-.104	-.108
	Digit ratio	-21.759	7.671	-.305	-2.837	.006		-.325	-.300

The hierarchical entry method is used so that the model derived from the full participant sample can be tested to see how well it performs on female sports participants only. It was found that only digit ratio out of the three candidate predictor variables, correlated significantly with athlete achievement rank for the female sport participants. This is a highly relevant finding, as only male participants have been investigated in previous research in regards to the negative correlation between 2D: 4D digit ratio and sport achievement rank.

Table 12:
A step-wise entry multiple regression of the predictor variables upon athlete achievement rank for the female sport participants only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2
1	(Constant)	27.430	7.319		3.748	.000	.105
	Digit ratio	-23.129	7.536	-.325	-3.069	.003	

A stepwise regression was performed to see if a better model could be constructed specifically for the predictor variables of the female sample. As with the previous hierarchical regression, none of the predictor variables other than digit ratio were found to significantly correlate with achievement rank and therefore have any significant influence on the variance between the digit ratio-achievement rank correlation.

This finding suggests that the 2D: 4D digit ratio of female sport participants is significantly negatively associated with their rank of participation in team sports over a range of contact intensities. The present findings also highlight the negligible influences of the other predictor variables on this digit ratio-achievement rank correlation.

Male sport participants:

For the simple regression for male sports players of digit ratio on rank, the correlation was r =-.344. This reveals that 11.83% of the variance in achievement rank is accounted for by 2D: 4D digit ratio in male sport participants, when only digit ratio was entered into the simple regression.

Table 13:
A hierarchical entry multiple regression of specific predictor variables upon athlete achievement rank for the male sport participants only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	Zero-Order	Part
1	(Constant)	4.311	.529		8.144	.000		
	Social potency	.134	.057	.267	2.335	.022	.267	.267
2	(Constant)	5.981	.752		7.949	.000		
	Social potency	.152	.055	.304	2.782	.007	.267	.302
	Mental rotation	-.150	.050	-.326	-2.981	.004	-.291	-.323
3	(Constant)	27.391	7.938		3.451	.001		
	Social potency	.144	.053	.287	2.738	.008	.267	.285
	Mental rotation	-.127	.049	-.275	-2.589	.012	-.291	-.269
	Digit ratio	-22.541	8.323	-.286	-2.708	.009	-.344	-.281

When a hierarchical entry method was used, all of the predictor variables entered (digit ratio included) were found to be significantly correlated with the athlete achievement rank of the male sport participants.

The SR of .285 for social potency when squared revealed that it accounted for 8.12% of the variance in rank, while mental rotation (SR=-.269) accounted for 7.24% of the variance in achievement rank when all the variance shared with the other predictor variables were removed. The semi-partial correlation (sr) between rank and digit ratio was -.281 which when squared (sr^2) revealed that 7.9% of the variance in achievement rank was accounted for by 2D: 4D digit ratio in male sport participants after all the variance shared with the other predictor variables was removed. The difference therefore between the two squared correlations (r^2-sr^2) reveals that 3.93% of the correlation between 2D: 4D digit ratio and achievement rank was moderated by the combined effects of the other predictor variables: social potency and mental rotation.

Table 14:
A step-wise entry multiple regression of the predictor variables upon athlete achievement rank for the male sport participants only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2
1	(Constant)	7.102	.665		10.682	.000	.085
	Mental rotation	-.134	.052	-.291	-2.565	.012	
2	(Constant)	5.981	.752		7.949	.000	.176
	Mental rotation	-.150	.050	-.326	-2.981	.004	
	Social potency	.152	.055	.304	2.782	.007	
3	(Constant)	27.391	7.938		3.451	.001	.255
	Mental rotation	-.127	.049	-.275	-2.589	.012	
	Social potency	.144	.053	.287	2.738	.008	
	Digit ratio	-22.541	8.323	-.286	-2.708	.009	

When a stepwise entry method was used, to see if a better model could be constructed specifically for the predictor variables of the male sample, only digit ratio, mental rotation and social potency of the predictor variables were found to significantly correlate with achievement rank (as in the previous hierarchical method).

Rugby players:

For the simple regression of digit ratio on rank, the correlation was r= .133. Therefore only 1.77 % of variance in achievement rank was accounted for by digit ratio for the rugby players, when only digit ratio was entered into the simple regression.

Table 15:
A hierarchical entry multiple regression of specific predictor variables upon athlete achievement rank for the rugby players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2	Zero-Order	Part
1	(Constant)	5.015	.632		7.933	.000	.020		
	Social potency	7.244E-02	.071	.142	1.017	.314		.142	.142
2	(Constant)	6.763	.880		7.687	.000	.147		
	Social potency	.114	.069	.224	1.654	.105		.142	.218
	Mental rotation	-.177	.065	-.365	-2.700	.009		-.315	-.356
3	(Constant)	6.228	12.108		.514	.609	.147		
	Social potency	.115	.072	.225	1.595	.117		.142	.213
	Mental rotation	-.178	.070	-.367	-2.543	.014		-.315	-.339
	Digit ratio	.562	12.679	.006	.044	.965		-.133	.006

When the hierarchical entry method was used, it was found that only mental rotation out of the three candidate predictor variables was significantly correlated (negatively) with achievement rank for the rugby players. Mental rotation accounted for 9.92% (R=-.315) of the variance in achievement rank.

Table 16:
A step-wise entry multiple regression of the predictor variables upon athlete achievement rank for the rugby players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2
1	(Constant)	7.392	.807		9.161	.000	.100
	Mental rotation	-.153	.065	-.315	-2.351	.023	

Out of all of the predictor variables entered into the stepwise regression, all but one were excluded because of lack of predictive ability. Only mental rotation was found to have a significant negative correlation with athlete achievement rank (as in the previous hierarchical method).

In both of the multiple regressions only mental rotation of all the predictor variables was found to have a significant (negative) influence upon the variance in athlete achievement rank for the rugby players. It should again be emphasised that this correlation was in the opposite direction to hypothesised and found in previous research literature. Disturbingly the same anomaly was found regarding the male sport participants also.

Football players:

For the football players, the simple regression of digit ratio on rank revealed a correlation of R=.588. When squared (R^2) this correlation revealed that 34.57 % of the variance in achievement rank was accounted for by 2D: 4D digit ratio, when only digit ratio was placed into the simple regression itself. This value is markedly high in comparison to the corresponding values from the rugby and basketball participants.

Table 17:
A hierarchical entry multiple regression of specific predictor variables upon athlete achievement rank for the football players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2	Zero-Order	Part
1	(Constant)	4.314	.497		8.688	.000	.043		
	Social potency	8.340E-02	.054	.209	1.538	.130		.209	.209
2	(Constant)	4.258	.875		4.865	.000	.044		
	Social potency	8.341E-02	.055	.209	1.523	.134		.209	.209
	Mental rotation	4.985E-03	.064	.011	.078	.938		.010	.011
3	(Constant)	38.873	7.024		5.534	.000	.359		
	Social potency	4.575E-02	.046	.114	.996	.324		.209	.113
	Mental rotation	6.820E-03	.053	.015	.129	.898		.010	.015
	Digit ratio	-35.462	7.158	-.569	-4.954	.000		-.588	-.561

Only digit ratio out of the candidate predictor variables entered, was found to be significantly correlated with athlete achievement rank.

Table 18:
A step-wise entry multiple regression of the predictor variables upon athlete achievement rank for the football players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2
1	(Constant)	40.461	6.770		5.977	.000	.346
	Digit ratio	-36.636	6.991	-.588	-5.240	.000	

The stepwise regression confirmed that only 2D: 4D digit ratio of the predictor variables was found to have a significant influence on the achievement rank for the football players (as in the previous hierarchical regression), as all the other predictor variables were excluded from the regression.

Basketball players:

For basketball players, the simple regression of digit ratio on rank revealed the correlation to be r=.308. Which when squared (r^2) revealed that 9.49% of the variance in achievement rank was accounted for by digit ratio, when only digit ratio was placed into the simple regression itself.

Table 19:
A hierarchical entry multiple regression of specific predictor variables upon athlete achievement rank for the basketball players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2	Zero-Order	Part
1	(Constant)	3.933	.461		8.536	.000	.131		
	Social potency	.147	.055	.361	2.658	.011		.361	.361
2	(Constant)	4.762	.867		5.494	.000	.154		
	Social potency	.146	.055	.359	2.648	.011		.361	.359
	Mental rotation	-6.866E-02	.061	-.153	-1.128	.265		-.158	-.153
3	(Constant)	24.731	9.126		2.710	.009	.236		
	Social potency	.124	.054	.304	2.287	.027		.361	.298
	Mental rotation	-9.760E-02	.060	-.218	-1.628	.110		-.158	-.212
	Digit ratio	-20.136	9.164	-.299	-2.197	.033		-.308	-.286

The hierarchical entry method revealed only the personality subscale of social potency and 2D: 4D digit ratio to have a significant influence upon achievement rank in basketball players. The simple correlation coefficients revealed digit ratio to account for 9.49 % of the variance in rank, while social potency was found to account for 13.03% of variance. The semi partial correlation (sr) between rank and digit ratio was -.286, which when squared (SR^2) revealed that 8.18% of the variance in rank was accounted for by digit ratio after all the variance shared with social potency was removed. The variance in rank accounted for by social potency was reduced to 8.88% when all the variance shared with digit ratio was removed. For digit ratio, the difference, therefore between the two squared correlations (R^2-SR^2) accounted for 1.31%, revealing that 1.31%, of digit ratio's relationship to rank was explained by the mediating influence of social potency.

Table 20:
A step-wise entry multiple regression of the predictor variables upon athlete achievement rank for the basketball players only

Model	Predictor Variable	B	Std. Error	Beta	t	Sig	R^2
1	(Constant)	3.933	.461		8.536	.000	.131
	Social potency	.147	.055	.361	2.658	.011	

The results of the stepwise method differed with those from the previous hierarchical method for the basketball players. The stepwise regression excluded digit ratio, which was previously found to be significant in the hierarchical method, with consequently only social potency being found to have a significant influence upon player rank. Further investigation revealed that digit ratio was barely significant ($P = 0.07$) in the hierarchical regression at the 10% level. In the stepwise regression the criterion for significance was the 5% level, hence digit ratio was excluded from this subsequent regression.

Summary and conclusions of the regression analyses

When comparing the male sport participants with the female sport participants, it was expected that the predictor variables would account for greater variance in rank for the male participants as these variables are considered testosterone-mediated, with the male participants having higher mean prenatal concentrations of testosterone (as represented by their lower mean digit ratios). This was found to be the case. Among male sport participants, digit ratio accounted for more variance in rank than among female sport participants. In addition, social-potency and mental rotation significantly influenced rank among male sport participants, whereas among female players they did not.

All of the significant effects of mental rotation on athlete achievement rank, however, were in the opposite direction to previously found in research (Manning and Taylor, 2001) and hypothesised in this current study, raising serious questions about the validity, reliability or administration of this measure (to be discussed later in this investigation).

An important finding was that, for the female sport participants, 2D: 4D digit ratio had a significant effect on the variance of their athlete achievement rank (10.56%). This is a novel finding as female participants have not been investigated under these circumstances before. This finding indicates the strength of 2D: 4D digit ratio as a predictor of athlete achievement rank even in female populations with characteristically higher digit ratios (and subsequent higher mean prenatal oestrogen concentrations and lower mean prenatal testosterone concentrations) than male populations.

None of the personality variables except social potency were found to significantly influence achievement rank for either sex or across the three different sport contact intensities (rugby, football, basketball). This finding is consistent with the lack of predictive validity found for achievement, harm avoidance and control in the previous three analyses.

It was expected (and consequently found) that the predictor variables of social potency, mental rotation and digit ratio would all have a significant influence on achievement rank across varying degrees of sport contact intensities, as these predictor variables are universally considered to be associated with high-rank in team sport. Not one of the three different sports investigated, however, showed all three of these predictor variables to simultaneously significantly influence athlete achievement rank.

Digit ratio was found to account for far more variance in rank for the football players than for basketball players. A possible explanation for this is that because football is a sport played at a more competitive level in Britain and British universities and also with a greater degree of contact intensity, its participants are expected to have lower digit ratios and hence higher prenatal testosterone, which will be consequently expected to exert a stronger influence upon rank than in the less competitive and contact intense basketball. This potential explanation is however undermined by the non-significant influence of digit ratio on rank among rugby players, despite the fact that university rugby is played at a markedly more competitive level with a greater degree of contact than university football. Another possible explanation could be that due to a limited (truncated) range of the digit ratio measures for the rugby and basketball participants, there was a lack of variance of data points which resulted in a lack of associated significant effects. This suggestion is given support by the fact that the football players had a noticeably higher standard deviation for their digit ratios (SD=0.2608) compared to the basketball and football players.

It is surprising that the predictor variables, all considered to be mediated by prenatal testosterone, when actually found to have significant influences upon variance in achievement rank, often did so completely independently of one another, revealing a complete lack of logical consistency. With regards to any of the participant sex or sport contact intensity subgroups, some predictor variables were found to have very strong associations with rank, while others were not found to be significant at all. The only sub-group, which had digit ratio, social potency and mental rotation simultaneously significantly influencing variance in rank, was the male sport participant group. This was not just because the male sample was larger, as there were actually more female sports participants than males. This is an interesting finding, as it perhaps suggests that only in male subjects, with their characteristic lower 2D: 4D digit ratio and correspondingly higher prenatal testosterone and lower prenatal oestrogen, will prenatal testosterone-mediated variables be of sufficient strength to simultaneously significantly influence sport achievement rank.

This may mean that for the female sports participants, their lower mean prenatal testosterone and higher prenatal oestrogen, as represented by their higher mean digit ratios, may cause the testosterone-mediated predictor variables to be insufficiently powerful enough to significantly influence their achievement rank. Probably other non-testosterone-mediated variables will have a more important influence on the rank of female athletes, such as physiological suitability to sporting success, as best represented in this current investigation by weight and height. Dedication to succeed and experience in sport may also be of greater importance for rank attainment in the female participants, which again are best represented in this current investigation by the secondary variables 'years played' and 'hours trained/played per week'.

This sexual dichotomy of the influences of the predictor variables on variance in athlete achievement rank may at least partially explain the lack of predicted outcomes for the three sport contact intensity categories, because female sport participants were blocked with male sport participants within these categories, therefore possibly masking significant findings. Expected findings may have occurred had just the male sports participants been investigated in these three different categories (as was demonstrated when the males were tested separately).

The overall findings from this analysis regarding digit ratio, support the hypothesis of 2D: 4D digit ratio as an important predictor of athlete achievement rank. The other major implication of this final analysis is the finding that the influence of digit ratio upon athlete achievement rank appears to be largely and surprisingly independent of the predicted mediating influences of the other predictor variables. This may mean that either 2D: 4D digit ratio has a somewhat direct effect on athlete achievement rank or that the variables that do mediate this influence were not incorporated in this current investigation as predictor variables.

Discussion

The purpose of the current study was to investigate the relative influences of 2D: 4D digit ratio, mental rotation ability and the specific personality variables: social-potency, achievement, harm-avoidance and control upon the 'athlete achievement rank' of university sports team players. This study also aimed to compare low ranking players (social/non-elite) with high-ranking players (serious/elite) and also to compare the combined sports players with a non-sports playing control group. The moderating influence of participant sex and the participants' 'sport contact intensity' (basketball, football and rugby) upon these predictor variables was also investigated. The aim was to test a proposed model, that the relationship between digit ratio and achievement rank is (partially) mediated by mental rotation ability and the psychological variables, all considered to be mediated by prenatal testosterone.

FINDINGS

The hypotheses of this study will now be reviewed chronologically and discussed in relation to the current findings and with previous research.

H1): <u>2D: 4D digit ratio will be negatively correlated with athlete achievement rank</u>

This relationship was expected because digit ratio (considered as a physiological manifestation of the ratio of prenatal testosterone to oestrogen) has been found to be a predictor of sports achievement, for times recorded in 800 and 1500m athletics races (Manning, 2002b), for down-hill slalom skiing races (Manning 2002a) as well as for sports achievement rank in a number of team sports including football rugby and hockey (Manning & Taylor, 2001).

This hypothesis was supported. The high-ranking sports participants were found to have significantly lower 2D: 4D digit ratios than the low-ranking sports participants, both when the non-sport participant group were included and excluded from the data analysis.

In this study, as might be expected, high-rank sports participants were also found to have significantly lower digit ratio's than the non-sport participants. It might have also been anticipated that the low-rank sport participants would have a lower digit ratio than the non-sport participants, however no significant difference was found between the two groups. It can be concluded that 2D: 4D digit ratio was found to discriminate high-rank sports participants from both low-rank sport participants and non-sport participants. Low level sports players and non-sport participants may not differ in their physiological sporting competence or potential. Rather, it is probable that their variation in sports participation may be a result of the influence of a number of environmental factors such as parental influence, competing leisure interests or lack of opportunity.

H2): <u>2D: 4D digit ratio will be negatively correlated with mental rotation scores</u>

This hypothesis was formulated as numerous studies have shown that higher concentrations of prenatal testosterone and lower concentration of prenatal oestrogen facilitate the development of the right hemisphere of the brain (Geschwind & Galaburda, 1985), which is functionally utilised for visual spatial ability including mental rotation ability (Grimshaw et al, 1995). Mental rotation scores have also been found to be directly negatively associated with 2D: 4D digit ratio in previous research (Manning & Taylor, 2001, Sanders, Soares and D'Aqulia, 1982).

This hypothesis was not supported. Digit ratio was not found to be significantly negatively correlated with mental rotation scores. Although this finding was contrary to extensive previous research, it is in accord with the findings of Coolican and Peters (2003) who also failed to establish this hypothesised relationship (regardless of the use of large mixed sex participant sizes). Without contradicting the previously cited research, the only possible explanation that can be given as to why the hypothesised correlation was not found, was that the mental rotation test used (Philips & Rawles, 1976) was not a valid/reliable measure of the sports participants' visual-spatial ability. Even though the test used was of an identical format to the two mental rotation tests used extensively in previous research, (Sheperd & Metzler, 1971; Vandenberg & Kuse, 1978) which found mental rotation to be significantly negatively correlated with 2D: 4D digit ratio (Manning & Taylor, 2001, Sanders et al, 1982). The one prominent difference between the tests was that the one used in the current investigation was notably shorter (two minutes compared to ten and fifteen minutes respectively) which may well have compromised its reliability as well as its construct and thus its predictive validity as a sport specific mental rotation measure.

H3): Mental rotation scores will be positively correlated with athletic achievement rank

Past research indicates that good visual spatial ability is strongly associated with sporting excellence in team sport players (Manning 2002, b). A player's ability to know where the ball is in relation to team-mates, opposition players, the goal area and the part of their body with which they are to strike it, is seen as highly beneficial towards team sport players performance. Previous research has shown mental rotation to be strongly correlated with athletic achievement rank in team sports (Manning & Taylor, 2001).

This hypothesis was not supported. In fact the opposite was found with low-rank sport participants having significantly higher mental rotation scores than the high-rank sport participants. This was only found when the non-sport participant group was excluded from the analysis and not so when they were included. The scoring of this measure was checked for possible errors, which were found not to exist. It is unclear why this hypothesis received no support. Even if mental rotation ability is not as important an influencing variable upon achievement rank as was expected, this does not account for the puzzling fact that a complete statistically significant reversal from the expected direction of correlation occurred. The questionable validity of the mental rotation measure as discussed earlier, may be implicated.

H4): The personality variable: 'social potency' will be negatively correlated with 2D: 4D digit ratio and positively correlated athlete achievement rank

Tellegen (1982) developed the personality subscale 'social potency' for his Multidimensional Personality Questionnaire (MPQ). From observing the correlations of the subscale with other personality inventories and their subscales (as described at the end of the introduction) as well as from the results of a cluster analysis of the content sorting of MPQ items by judges (Tellegen, 1981), as summarised in Table 1 of the introduction, social potency can be concluded to encompass a number of related personality traits, these are: extroversion, assertiveness, dominance and sociability.

Free testosterone (from saliva and blood) has been found to have the same effects as 2D: 4D digit ratio across a wide range of variables, mentioned in the introduction (Benbow, 1998; Gotestam, 1990; Grimshaw et al, 1995; Kimura and Hampson, 1994). There is far more research regarding correlations between free testosterone and personality variables compared with 2D: 4D, consequently, much of the evidence for the hypotheses regarding digit ratio-personality correlations was drawn from free testosterone-personality studies.

The first part of this multiple hypothesis was formulated because personality traits considered to be highly correlated with or subsumed by social potency have been found in previous research, to be associated with testosterone and 2D: 4D digit ratio. Free/circulating testosterone concentrations are positively correlated with the personality traits of dominance (Mazur & Booth, 1988), social dominance (Schaal, Tremblay, Soussignan and Susman, 1996), assertiveness (Archer, 1991) and extroversion (Daitzman & Zuckerman, 1980) as well as being negatively associated with reticence (sociality reversed) (Dabbs, 2000). Male 2D: 4D digit ratio was significantly negatively correlated with perceived dominance (Neave et al, 2003) and among women, Wilson (1983) found female participant self-reports of assertiveness to be negatively associated with their self-measured digit ratios. This previous research indicates that participants with low 2D: 4D digit ratios will score higher on social potency.

Regarding the second part of this multiple hypothesis, previous research has also found some personality traits encompassed by social potency to be positively associated with sporting success and athlete achievement rank. Extroverts have been found to be more likely to excel in many different types of team sports (Eysenk, 1979, Eysenck, Nias and Cox, 1982), Olympic athletes were found to score higher on extroversion than non-Olympic athletes (Warburton & Kane, 1966) and high dominance scores have been linked to athletes' success (Fletcher & Dowell (1971). Based upon this evidence it was expected that higher-ranking sport participants would score higher on social potency than lower ranking sports participants, as was hypothesised.

This multiple hypothesis was supported. Social potency was indeed significantly negatively correlated with 2D: 4D digit ratio as well as being significantly positively correlated with athlete achievement rank.

H5): The personality variable: 'achievement' will be negatively correlated with 2D: 4D digit ratio and positively correlated with athletic achievement rank

Cluster analysis of the content sorting of MPQ items by judges (Tellegen, 1981) as well as correlations between personality inventories and their subscales with the MPQ subscale of achievement (Patrick et al, 2002),(see introduction regarding both) suggest that achievement encompasses a number of personality traits including achievement-orientation, motivation, persistence, competitiveness and 'hard working behaviour'.

There is some evidence to suggest that the 'achievement' variable is negatively correlated with digit ratio. Male participants (who have lower mean 2D: 4D digit ratios) were found to score higher on 'achieving tendency' from the 'Measures of Achieving Tendency Scale' (Mehrabian and Banks, 1978) as well as scoring higher on 'competitiveness' on the 'Personal Attribute Questionnaire (Spence et al, 1974) than female participants (who have higher mean 2D: 4D digit ratios). More direct evidence comes from the findings that 'achievement orientation' was found to be positively correlated with free testosterone and negatively correlated with free-oestrogen concentrations in participants (Daitzman & Zuckerman, 1980), as was the personality trait, 'competitiveness' also (Zuckerman, 1994). Based upon this evidence, it was expected that participants with lower digit ratios would score higher on the personality variable of 'achievement' than participants with higher digit ratios.

Achievement was also expected to be positively associated with athlete achievement rank. Evidence to support this, is as follows: Athletes scored higher on 'achievement' in comparison to non-athletes (Balazs & Nickerson, 1976). The variables: 'motivation', 'commitment' and 'hard-work' were positively associated with exceptional sport success (Signer & Janelle, 1999). Athletes with strong motivation to achieve success were found to perform better and achieve higher rank than athletes with strong motivation to avoid failure (Halvari & Thomassen, 1997). Elite athletes (professional or international) reported significantly higher 'achievement motivation' in comparison to non-elite athletes (Davis & Mogk, 1994; Vanek & Cratty, 1970).

This hypothesis, however, was not supported. Achievement was not found to significantly correlate with athlete achievement rank or digit ratio. It is possible that the measure of achievement used in this current investigation had a poor predictive validity within a sports context as it was drawn from a generalised personality inventory. This is supported by its consistent predictive failure as a measure throughout this current investigation. The need for a more sport specific personality inventory will be mentioned later in this investigation. As the sports participants' digit ratios were still significantly correlated with their athlete achievement rank, it can be concluded that this association is independent of the participants' scores on the MPQ subscale of achievement.

H6): The personality variable: harm-avoidance will be positively correlated with 2D: 4D digit ratio and negatively correlated with sport contact intensity

Cluster analysis of the content sorting of MPQ items by judges (Tellegen, 1981) and personality inventories and their subscales that are strongly correlated with the MPQ subscale of harm-avoidance (Patrick et al, 2002) suggest that Tellegen's (1982) subscale subsumes a number of personality variables, including: sensation seeking (reversed), fearfulness, venturesome (reversed) and risk avoidance.

No previous research has been undertaken regarding the relationship between harm avoidance (or its associated personality variables) and 2D: 4D digit ratio. Supporting evidence for the first part of this hypothesis comes from studies regarding the relationship between free-testosterone and personality variables either strongly correlated with or subsumed by harm avoidance. Free-testosterone levels are strongly positively correlated with sensation seeking scores in males (Gerra et al, 1999). Plasma testosterone is positively correlated with monotony avoidance scores on the 'Karolinska Scales of Personality' sensation seeking scale (Mattsson, Schalling, Olweus, Low & Svensson, 1980). High sensation seekers were found to have unusually high levels of free-testosterone (Daitzman et al, 1978).

The second part of this hypothesis, that harm avoidance is negatively correlated with sport contact intensity, was derived from the following evidence: Those who participate in explosive sports, such as football or hockey score lower on arousal avoidance than those who participate in endurance sports, such as long distance running and rowing (Sveback & Kerr, 1989). Contact sport players scored higher on sensation seeking than non-contact sport players (Fowler et al 1980). High-risk sport participants scored significantly lower on arousal avoidance than low risk-sport participants (Murgatroyed et al, 1978). Participants in high-risk/contact sports scored higher on sensation seeking than those who participated in low-risk/non-contact sport (Zuckerman, 1983).

This hypothesis was not supported. The personality subscale of 'harm-avoidance' was not found to be positively correlated with 2D: 4D ratio or negatively correlated with sport contact intensity. Again, this null finding may be due to the variable's poor predictive reliability and validity within a sports context as indicated by its consistent predictive failure as a measure throughout this current investigation. As the sports participants' digit ratios were still significantly negatively correlated with athlete rank, it can be concluded that this relationship is independent of the participants' scores on harm-avoidance.

H7): <u>The personality variable: 'control' will be positively correlated with 2D: 4D digit ratio and negatively correlated with sport contact intensity</u>

From observing cluster analysis of the content sorting of MPQ items by judges (Tellegen, 1981) and correlations with personality inventories and their subscales, Tellegen's (1982) MPQ subscale of control can be concluded to subsume a number of personality variables, including: impulsivity (reversed), dis-inhibition (reversed), planning and self-control.

No research exists regarding the relationship between 2D: 4D digit ratio and the personality subscale of control (or any of the personality variables it subsumes). Again evidence to suggest the association was taken from free-testosterone studies. Daitzman et al (1978) found dis-inhibition (negatively associated with control) to correlate significantly with the male sex hormone testosterone. High impulsivity and low self-control were also found to correlate with testosterone (Daitzman & Zucherman, 1980). Dabbs, Hopper and Jurkovic (1990) found saliva-testosterone to be negatively correlated to 'control' scores in male college students. Based upon this evidence it was expected that sports participants with higher digit ratios would score higher on control than participants with lower digit ratios.

Research evidence suggests a negative correlation between control and sport contact intensity. Sveback and Kerr (1989) found that those involved in paratelic (explosive/contact) sports scored lower on 'planning' than those who played non-paratelic (non-explosive/non-contact) sports. Zuckerman (1983) found high-risk sports players to score higher on 'impulsiveness' than low-risk sport players. Schroth (1995) found that players of lower contact intensity sports (soccer and rowing) scored lower on 'impulsivity' than those who participated in higher contact intensity team sports (rugby and lacrosse). Based upon this evidence it was expected that the contact intensity of the participants' sports would be negatively correlated with their 'control' scores.

This hypothesis was not supported. Control was not found to be associated with either 2D: 4D digit ratio or sport contact intensity. The absence of these relationships echoes the pattern for the other personality variables previously discussed.

H8): Male sports participants will have lower 2D: 4D digit ratios and higher mental rotation scores than female sports participants

The first part of this hypothesis was formulated from the following evidence: Manning (2002a) in an extensive review of associated research, concluded that males have characteristically low 2D: 4D digit ratios (markers for uterine environment high in testosterone and low in oestrogen) while females conversely were found to have characteristically high 2D: 4D ratios (markers for a uterine environment low in testosterone and high in oestrogen). This is supported by many studies including Austin et al (2002) and Manning et al (1998). The sex difference in digit ratio has been found to be highly stable and consistent in cross-national and cross-cultural studies (Manning, 2002b).

Male sport participants were expected to perform better on mental rotation tasks than female sports participants. Males have higher prenatal concentrations of testosterone and lower prenatal concentrations of oestrogen than females and this facilitates the development of the right hemisphere of the brain known to be associated with visual spatial ability (Geschwind & Galaburda, 1985) thus enhancing males' performance on mental rotation tasks. A considerable body of research supports this, with visual spatial and in particular mental rotation tasks being found to produce strong sex differences favouring males (Halpern, 1986, 1992; Manning and Taylor, 2001; Wilson et al 1975). This sex difference has been found to be robust across simple or complex patterns (Bryden & George, 1990) and to remain unchanged over time (participants' life time) (Masters and Sanders, 1993).

This hypothesis was partially supported. It was found that the male sports participants did have significantly lower digit ratio than the female sports participants but no significant sex difference was found with regards to mental rotation scores. This latter finding was not unexpected given the earlier finding that mental rotation ability was negatively correlated with athlete achievement rank (opposite to hypothesised), thus already raising doubts about the validity, reliability or administration of the measure.

H9): <u>Male sports participants will score higher on the personality variables: 'social-potency' and 'achievement' and lower on the personality variables: 'control' and 'harm-avoidance' in comparison to the female sports participants</u>

Evidence for the formation of this penultimate hypothesis will be presented for each personality subscale consecutively:

Social potency: Tellegen (1982) found male college students to score higher than female college students on the social potency sub-scale used in this current study. This finding is further supported by Csatho et al (2002), who found male participants to exhibit more assertive behaviour than female participants.

Achievement: The achievement subscale used in this investigation was found by Tellegen (1982) to be higher for male compared to female college students. Other research has shown males to score higher on 'competitive behaviour' (Csatho et al 2002), 'achieving tendency' (Mehrabian and Banks, 1978) and 'competitiveness' on the Personal Attribute Questionnaire (Spence et al, 1974).

Harm-avoidance: Female college students were found to score higher than male college students on the harm-avoidance sub-scale used in this current investigation (Tellegen, 1982). Males have also been found to score higher on 'venturesome' and 'sensation seeking' (both negatively correlated with harm avoidance) than females (Zuckerman, 1991).

Control: Tellegen (1982) found female college students to score higher than male college students on the control personality sub-scale used in this current investigation. In other previous research, males have also been found to score significantly lower on 'control' (Daitzman & Zucherman, 1979) and higher on 'dis-inhibition' (Zuckerman, 1978; Davies & Mogk, 1994) than females.

This hypothesis was supported only partially. Of the four personality variables used in this study, only social-potency showed a significant sex difference in the hypothesised direction (male sport participants scored significantly higher). As achievement, harm avoidance and control were all found to consistently lack predictive validity with regards to digit ratio, achievement rank and sport contact intensity, it was not surprising that all three showed no significant sex differences.

It is surprising that, even though all four of the personality sub-scales were taken from the same inventory (Tellegen's MPQ, 1982), that only one variable (social potency) would be a valid predictor of both achievement rank and sex. This highlights the predictive strength of social potency and its associated personality variables with regards to these variables and also implies that the predictive failure of the other personality variables incorporated, is less likely to be due to the actual inventory administered being inadequate. A possible explanation for why the expected sex differences did not occur for the achievement, control and harm avoidance variables may be that the research evidence used to formulate this hypothesis only showed significant sex differences on these or associated variables in the general population. These findings may not transfer to the possibly characteristically different population of sports participants, where significant sex differences on these personality variables may be much less prominent or not occur at all. The MPQ may be a much less appropriate measure within this alternative sporting context. This suggestion, regarding diminished sex differences among athletes, is supported by the findings that more successful female athletes are likely to have personalities that more closely resemble those of men (Butt and Shroeder, 1980; Popma, 1980).

H10): The expected negative correlation between 2D: 4D digit ratio and athlete achievement rank will be (partially) mediated by the mental rotation and personality variables of the sport participants

This final hypothesis was formulated from the proposed model of influences on athlete achievement rank (fig 1) presented at the start of the introduction, which itself made an attempt to account for the documented negative correlation between digit ratio and athlete achievement rank (Manning and Taylor, 2001). Digit ratio is a physiological marker of prenatal testosterone, which is considered to mediate (at least partially) mental rotation ability and the specific personality variables incorporated in this study. These predictor variables in turn are considered to directly influence the achievement rank of sport participants. Evidence for all of these individual interactions is presented earlier in this investigation. Consequently it was expected that the predicted digit ratio-achievement rank correlation in this current investigation would at least partially be mediated by these predictor variables.

This hypothesis was only partially supported. Of the six predictor variables entered into the stepwise multiple regression for the sports participants, only three of these variables (2D: 4D digit ratio, mental rotation and social potency) were found to be significantly correlated with achievement rank. Of the 12.46% (R^2) of variance in achievement rank accounted for by the sports participants' digit ratios, only 2.66% (R^2-SR^2) of this effect was explained by the influence of the predictor variables social potency and mental rotation, of which, as mentioned previously, correlations between mental rotation and achievement rank were negative and hence in the opposite direction to hypothesised. This does indicate that the correlation between digit ratio and achievement rank is highly independent of the influences of the predictor variables, but may indeed be mediated by the influence of alternative variables not included as predictor variables in this study. This is indicated by the finding that a greater 6.65% of the variance in digit ratios influence on achievement rank was caused by the mediating influence of the secondary variables: hours trained/played per week and years played.

Research Question): To investigate the stability of the proposed model of influences on achievement rank, across the moderating variable influences of participant sex and sport contact intensity

The stability of the proposed model of predictor variable influences on achievement rank (fig 1) presented at the start of the introduction of this current study, was investigated by observing its variance in predictive ability for the sports participants across the moderating variables of participant sex and sport contact intensity (basketball, football, rugby). The full analysis and discussion of findings is presented in full in the results section of this current study. Each moderating variable will now be addressed consecutively with regards to the specific findings summarised from the sequence of multiple regressions performed (simple, hierarchical and stepwise) for the predictor variables in the final fourth data analysis.

Female sport participant: Only digit ratio was found to have a significant correlation with achievement rank, accounting for 10.56% of its variance. This was a novel finding as only males have been investigated with regards to digit ratio-achievement rank correlations before.

Male sport participant: Digit ratio (7.9%), social potency (8.12%) and mental rotation (7.24%) all significantly correlated with achievement rank (as indicated by the relevant percentages within brackets), when all the variance shared among these variables were removed. Social potency and mental rotation only accounted for 3.93% of the variance in digit ratio's correlation with achievement rank

Rugby players: Only mental rotation was found to significantly correlate with achievement rank, accounting for 9.92% of its variance. This correlation, however, was in the opposite direction to hypothesised (as for the male sports participants).

Football players: Only digit ratio was found to have a significant association with achievement rank, accounting for 34.57% of its variance, a markedly high value.

Basketball players: Only social potency was found to have a consistent significant influence upon achievement rank, accounting for 13.03% of its variance.

As can be seen, none of these (moderator variable) sub-groups were found to completely conform to the proposed model. This has been suggested, among other possibilities, to be due the fact that the predictor variables were testosterone-mediated and consequently the female participants, had prenatal testosterone concentrations too low to instigate the predicted correlations. Previously mentioned issues regarding the reliability and the validity of the personality variables and the mental rotation measure were also expected to have contributed to the lack of experimental support for the proposed model across the moderating variable influences of participant sex and sport contact intensity. The conclusions of these findings are presented in full detail at the end of the fourth analysis in the results section of this current study.

The implications of the current findings

This current investigation supports previous research, much of it by Manning, that 2D: 4D digit ratio is both sexually dimorphic and an effective predictor of sports achievement rank in team sport participants. As hypothesised, the present study found that higher-ranking sports participants and males had significantly lower digit ratios than lower ranking sports participants and females respectively. It was also found that high-rank sport participants had significantly lower digit ratio than non-sport participants. 2D: 4D digit ratio was found to account for 12.2 per cent of the variance in achievement rank of the sports participants (as revealed by analysis of variance in the first analysis section).

An important finding of this study was that 2D: 4D digit ratio was also found to be a highly significant predictor of achievement rank for female sport participants, with 10.56 per cent of their variance in achievement rank being accounted for by the digit ratios of the female sport participants. This is a novel research finding which indicates that even in a participant population characterised by higher 2D: 4D digit ratios (and hence higher prenatal oestrogen and lower prenatal testosterone measures relative to men) digit ratio was still found to discriminate high from low ranking female sport participants. Further research is necessary to confirm the replicability of this finding.

As hypothesised, the personality variable social-potency (encompassing assertiveness, extroversion, sociability and dominance) was found to be significantly higher for high-ranking sports participants and males than for lower ranking sports participants and females. This would suggest a correlation between social-potency and digit ratio, as digit ratio was also found to show significant rank and sex differences. This was confirmed, revealing that sport participants with lower 2D: 4D digit ratios, scored significantly higher on social potency. These correlations support the findings, among others, of Mazur and Booth (1998) and Schaal et al (1996), that testosterone (both circulating and prenatal) is positively correlated with 'dominance', 'assertiveness', and 'social-dominance'.

Of the predictor variables examined in this current investigation, the primary variable 2D: 4D digit ratio and social-potency were found to have the greatest influence on athlete achievement rank among the sport participants. From observing the eta^2 scores from the relevant ANOVAs, digit ratio was found to account for 12.2 per cent and 'social-potency' 5.2 per cent of the variance in athlete achievement rank.

Despite the correlation between digit ratio and social potency, multiple regression revealed limited common variance with the outcome measure of athlete achievement rank. Digit ratio alone accounted for 12.46 per cent of the variance in athlete achievement rank and this was only reduced to 9.8 per cent when the combined variance shared with both social potency and mental rotation, the only other predictor variables found to significantly influence rank, was removed. This was unexpected as the predictor variables were all considered to be testosterone-mediated and it was therefore expected that they would account for a large proportion of the relationship between 2D: 4D digit ratio and achievement rank. It is possible that variables were omitted that may have shown a stronger mediating effect on the digit ratio-rank correlation. This is supported by the finding that 6.65% of the variance in digit ratios influence on achievement rank was caused by the mediating influence of the secondary variables: hours trained/played per week and years played. Further research is clearly needed to establish the psychological and biological mechanisms, which link prenatal testosterone with sports achievement rank.

The moderating variable of sport contact intensity was unexpectedly found to cause no significant variation in any of the mean predictor variable scores for the participants of the three different sports tested. Participants from different sports were only found to differ significantly on the secondary variable of weight, height, years played and hours trained/played per week. This suggests that prenatal sex hormone concentrations and the mediating mental and psychological variables associated with them are of equal importance to achievement rank in low, moderate and high contact team sport participants, who only differed, on the variables associated with the differing physical and competitive requirements of the sport they played.

No such consistency across the three sports was found with regards to the predictor variables, when their influences upon achievement rank were estimated from multiple regressions. For rugby players, the only predictor variable to significantly influence rank was mental rotation, independently accounting for 9.92 per cent of the variance. However the relationship was negative and thus in the opposite direction to hypothesised. For football players the only significant predictor variable was digit ratio, independently accounting for a remarkable 34.57 per cent of variance in achievement rank. For basketball players, only social-potency consistently had a significant influence on achievement rank, independently accounting for 13.03 per cent of its variance. A partial explanation for this lack of consistency across the different sport contact intensities was given in regards to the occurrence of a limited range/variance of digit ratio measures for the rugby and basketball participants resulting in a lack of associated significant effects. This suggestion was supported by the football players' comparably higher standard deviation for their digit ratios. This explanation does not, however account for the variation in the influences of mental rotation and social potency on achievement rank across the three sport contact intensities, which may be due to the highly apparent questionable validity of these measures.

This current investigation also highlights the important influence of a participant's physical characteristics upon achieving high rank status in team sports. Analysis of variance revealed both the secondary variables of 'height' and 'weight' to have a highly significant association with achievement rank, explaining 5.2 per cent and 5.8 per cent of the variance in rank among sports participants respectively. This finding emphasises the importance of physiological predisposition to sporting success (Cowart, 1987; Singer and Janelle, 1999). These physiological variables of height and weight (as well as physique and muscularity) are likely to have a genetic component: "The heritability of stature is very high, perhaps 95%" (Singer and Janelle, 1999, pp125), as well as being able to be significantly altered by environmental influences. Height is primarily environmentally influenced by diet in adolescence and weight, within a sporting context, is influenced by diet and training (specificity, intensity and regularity).

When the secondary variables, including height and weight, were entered into a stepwise multiple regressions with the predictor variables (see table 10) to ascertain the extent of their mediating influences upon 2D: 4D digit ratio's correlation with achievement rank, only years played and hours trained/played per week of the secondary variables were found to have such a mediating influence. This leads us on to the most significant predictive variables of athlete achievement rank within this current investigation.

The two variables found to separately account for the highest variance in athlete achievement rank, were years played and hours trained/played per week. The number of years the athletes had played their sports explained 17.4 per cent of the variance in their athlete achievement rank, while the number of hours per week spent playing and training for their sports accounted for 14.5 per cent of the variance in their athlete achievement rank. This indicates the importance of the skill acquisition and improvement achieved through sheer longevity of playing and intensity of training in team sports and the associated achievement rank status. These two variables accounted for more variance in rank individually than 2D: 4D digit ratio. As mentioned previously, these two secondary variables were also found to have the greatest mediating effect, of all the dependant variables, on the correlation between digit ratio and athlete rank, accounting for 6.65 per cent of the association, indicating that they are likely to be partially mediated by prenatal testosterone concentrations. This was confirmed by observing relevant data from the inter-correlation matrix performed, which revealed digit ratio to be significantly negatively correlated with years played ($R=-.218$, $P< .01$). No significant correlation, however, was found with regards to hours trained/played per week.

These findings coincide with empirical evidence from previous research. DeGroot (1965) and Chase and Simon (1973) both reported the single biggest influence on sports expertise to be training/practise, arguing that expert performance is due to the athletes' acquisition and retrieval of vast amounts of task-relevant information resulting from many years of experience in their chosen domain of expertise. This is also reinforced by Paul & Glencross (1977) who concluded that practice develops a sophisticated knowledge structure, which they found to differentiate experts from novices within a sporting context.

The effect of training upon sports rank will obviously depend on the quality of training as well as the participants' genetic predisposition to benefit from that training. Bouchard, Malina & Perusse (1977) concluded that there is strong evidence for an interaction between genotype and responsiveness to training, stating that an identical training programme may result in very little improvement in one individual and a great deal of improvement in another. The genetic predisposition to benefit from training may be associated with prenatal testosterone concentrations.

It should be noted however, that the specific direction of influences in correlational relationships is unknown. This is known as the 'cause and effect' problem in research. For example, when hours spent training per week is found to be correlated with athlete achievement rank, it is unknown whether an individual's amount of training has increased their rank or whether an individual who has achieved higher sports rank (due to other reasons) has to train more in consequence. This problem will beset many correlations, except those, which include variables where the direction of influence is unequivocal, such as digit ratio and post adolescent height.

Another novel finding to emerge from this current investigation was the paucity of significant differences between non-sports participants and sports participants. Much previous research has assumed, often with out empirical basis, that non-sport participants score lower than sport participants on variables associated with sporting success and achievement rank. A unique feature of the design of this current investigation was the inclusion of non-sports participants who were compared with both low and high-ranking sports participants allowing elaborate cross comparisons to be made between these three different groups. The present findings raise serious questions about the assumption that non-sports players lack the underlying qualities necessary for sporting ability. Non-sport participants did not differ significantly from low ranking sports participants on their variable scores for digit ratio and weight, and did not differ significantly from both the high and low ranking sports players on their variable scores for any of the four personality variables, height, parental ethnicity and mental rotation. Often the mean scores for the non-sport participants were intermediate between those for the differing sporting ranks. This suggests that people who do not play sports, differ little from those who do in terms of many success-related psychological, physiological and mental variables. The widespread assumption that people do not play sports because they lack aptitude for them may not necessarily be the case (except possibly regarding 2D: 4D digit ratio). It may be that environmental as well as physiological variables play an important role in the instigation of sport participation. In support of this, Bouchard, Malina & Perusse, (1997) found that children of physically active parents tend to be 5.8 times more likely to actively participate in sports than the children of inactive parents.

Interestingly, the only predictor variable on which non-sport participants significantly differed from sports participants (albeit only with the high-ranking sports performers) was digit ratio, considered to be the primary influencing variable in the proposed model of influences on athlete rank. It is this one variable (as a physiological marker of prenatal oestrogen and testosterone concentrations), which was considered to mediate all the other predictor variables: mental rotation and specific personality variables with respect to their influence upon athlete achievement rank. This mediating influence was highly unsupported by this current investigation, indicating that the chief effect of digits ratio's influence upon athlete achievement rank is either direct or at least is not substantially mediated by any of the predictor variables that were included in this study.

It has been suggested that a major reason for 2D: 4D's success in distinguishing between sport and non-sports participants, as well as between low-ranking and high-ranking sports participants, is the genetic predisposition to good health associated with higher prenatal testosterone and thus with having a lower digit ratio. Manning in a personal correspondence (email, 12-11-03) stated that the main cause of the correlation between digit ratio and sports achievement rank was due digit ratio's association with increased cardiovascular efficiency (in men). Previous research, has indeed, demonstrated that the benefits of low digit ratio include the formation of an efficient cardiovascular system and, in consequence, reduced risk of heart attacks (Manning & Bundred, 2000; Rossano, 2000). In contrast however, Manning's earlier research, (2002b) presented evidence which linked low digit ratio with increased prevalence of breast, ovarian, prostate, lung and colon cancer, as well as susceptibility to malaria, tuberculosis and HIV infections. Even though direct unequivocal evidence is lacking for some of these proposed associations, direct evidence does exist regarding links between low digit ratio and skin ailments. Caucasian participants with low 2D: 4D digit ratios were found to have a higher susceptibility to sunburn, athletes' foot and eczema (Manning, Bundred and Mather, 2003). It therefore appears that the genetically predisposed health benefits of low digit ratio seem to be considerably out-weighed by the many potential and severe associated health costs.

Possible ethical implications of these findings

Two possible major ethical implications, as suggested in the introduction, arise from the findings that 2D: 4D digit ratio is a credible predictor of athlete achievement rank. The first is the use of digit ratio as the sole criteria for sports team selection procedures and the second is the use of digit ratio measurements as a factor contributing to the occurrence of 'player poaching'.

With an increasing prevalence of research supporting 2D: 4D digit ratio as a significant predictor of sporting excellence, there is a worrying possibility that professional or international sports players could begin to be 'fired or hired' on the isolated grounds of their digit ratio measurements. A similar situation has already occurred within corporate hiring for decades, where some companies have incorporated psychometric testing into applicant hiring procedures, even though the validity of these measures in predicting actual job competency is highly unfounded and questionable (Murphy and Davidshofer, 2001).

Because environmental influences such as coaching, parental encouragement and injury prevention are considered extremely important in the developing of sporting excellence, it would be dangerously naïve to ignore these factors, alongside current sport performance profile, when making decisions about either recruiting or terminating the employment of a professional athlete. An individual may have extremely favourable digit ratio measurements for sport success but, due to the presence or absence of, certain environmental variables, may never reach this potential of sporting excellence.

'Player poaching' is the coaxing of talented sports players by wealthy national or club sides with financial rewards that cannot be matched by their poorer (native) national or club sides. It is especially prevalent in international football and rugby. The New Zealand national rugby side has been responsible for this act for years, offering scholarships at top New Zealand public schools to South Pacific Islanders who show sports potential, or, at older ages, offering lucrative sports contracts. After four years, the immigrant athlete can apply for citizenship and play for their new country. This was the case for Jonah Lomu, the New Zealand rugby wing. France has been responsible for player poaching in football, particularly from former French African and Caribbean Colonies, notable examples being Patrick Viera (from Senegal) Thierry Henry (from Martinique) and the French captain Zenidane Zidane (from Algeria). Some English premiership football sides have 'feeder' clubs in poorer continents such as Africa, where young Africans who show outstanding potential are enticed to play in England. This phenomenon may become of increasing concern as more research evidence is published regarding the reliability and validity of digit ratio as an indicator of potential sporting excellence. The use of 2D: 4D digit ratio measures may increase the frequency of 'player poaching', and thus the severity of its consequences. Developed national and club sides may be far more tempted to recruit youth players from poorer countries if there is a reliable way of knowing that the individual will achieve great sporting success. Currently, for every one of these recruitments that pay off, many do not (at great financial loss). To stop a possible epidemic, which would prevent some of the poorer nations from fielding credible national sides, the relevant national bodies and associations need to lay down stringent preventative rules and regulations.

Limitations

Due to the nature of this investigation with a large number of comparisons and correlations being investigated, there was a likelihood that chance significance or 'type one errors' may occur. A few unexpected findings did occur that had no direct and obvious explanation, however they caused no major implications with regards to this current investigation. These unexpected findings include: social-potency being significantly correlated with both years played and hours trained/played per week;

achievement being significantly correlated with 'hours trained/played per week; and mental rotation being found to be significantly correlated with achievement.

There was only one finding that really contradicted the theoretical and research foundations of this current investigation and consequently one of the experimental hypothesis. This was the finding that low-rank sports participants scored significantly higher than high-rank sports participants on the mental rotation test. I have already suggested that a possible explanation may be that the mental rotation measure used had poor construct validity for measuring mental rotation ability specifically associated with sports participation. Pencil-and-paper mental rotation tasks may not be useful measures of the dynamic spatial ability necessary for success in team ball sports and thus do not effectively capture the spatial abilities of the sports participants as they are used in real time on the pitch within their specific context. Manning and Taylor (2001), however, using a mental rotation test of identical format, found that men with higher mental rotation scores were of higher sporting rank. As with the personality trait inventory, what is needed is a mental rotation test that is specifically designed to accurately measure the specific variable as it is expressed on the sports field.

If indeed the unexpected negative correlation between mental rotation and rank was valid, the fact that digit ratio was still negatively correlated with achievement rank implies that team sports players may have a low mental rotation ability and still achieve high rank status (even though mental rotation is a variable considered to be highly beneficial to sporting performance), provided their digit ratio and social potency values are favourable to success.

The validity and generality of the findings from this current investigation

In this investigation, the participant base spanned a variety of team sports, across a continuum of contact intensity with approximately equal numbers of each sex and a wide range of achievement rank represented. The sport participant categories (non-sport, basketball football and rugby), even when split by sex, had a minimum participant group size of 21 participants. Ideal statistical power for analysis is dependent upon very large samples. The participant sizes for this current investigation were considered appropriate with regard not only to the limited time scale available for research and in comparison to the average participant sizes used by Manning in his research but also to allow valid and powerful statistical analysis.

The sampling problem of 'volunteer bias' was not really apparent in this current investigation. Testing was negotiated with team coaches and captains and was then participated in by the sports teams as a whole, being incorporated into training sessions or pre-match preparations, even though all participants gave individual consent and were informed of their right to withdraw at any time. The non-sport participants were recruited from student classes and workshops randomly.

Limitations and weaknesses of this current study

Of the four MPQ personality subscales used in this current study, only social potency was found to have any predictive utility. Interestingly however, numerous significant correlations occurred among the personality variables themselves. Both control and harm-avoidance were negatively correlated with social-potency and positively correlated with one another. This suggests that, even though the four personality variables are associated with one another in an expected way, they may not (with the exception of social potency) have been sufficiently context-specific to show associations with participant sex, rank and sport contact intensity among team sports participants. The MPQ inventory, which the personality variables were drawn from, was selected because of its well-established reliability and validity with regards to the general population. More sports specific inventories were considered, but disregarded due to a lack of suitability to the specific demands of this current investigation, in comparison, and due to being far less established measures in research. Future research in this field could usefully develop personality tests (using behavioural, physiological or paper-and-pencil measures) that are geared explicitly to the trait as it is expressed in sporting competition. They could be critically compared to existing 'off the shelf' tests developed for the general population in terms of their predictive ability.

It is acknowledged that the measurement circumstances for data collection were not ideal. When teams were tested before matches, a preoccupation with the oncoming event may have reduced the concentration and increased the anxiety of some participants. Likewise when participants were tested after training and matches, the associated fatigue may have again reduced the participants' concentration and motivation. This may have had some influence upon their performance on the various tasks and may have contributed to the absence of some expected correlations, such as between rank and mental rotation. As has been shown, significant correlations were found between rank and digit ratio, the latter being the only measure that participants did not complete themselves. To combat this potential source of error, in future, researchers should collect data only before unimportant training sessions or on days completely unrelated to training and matches. Regarding this previously mentioned design flaw, it should be noted that as long as the effect of various testing circumstances was randomly distributed across the sample, it should only have lead to greater random error, which might have depressed some correlations, but not reversed them.

It was also not possible to adequately investigate the influence of participant ethnicity on many of the other variables, as over 90 per cent of the participants were Caucasian. Many of the sports teams lacked a single non-Caucasian participant. Consequently ethnic variation among the non-Caucasian participants could not be validly statistically analysed because the group sizes were too small. As a result, the various different non-Caucasian categories were collapsed into a single non-Caucasian category to allow statistical comparisons to be made between the Caucasians and non-Caucasian participants. This was far from ideal as it prevented investigation of the possible variation between non-Caucasian sub-groups.

The measuring of participant digit ratio was stringently standardised throughout data collection to maintain the validity and reliability of the measures. Photocopies of the participants' hands were taken to measure their digit ratios in response to Manning (2002b) who stated that photocopied digit ratio measurements are as reliable as those taken directly from hands. The photocopies were favoured as they allowed participants' digit ratios to be measured slowly and precisely, with each ratio being re-measured to check for errors. Measuring procedures and techniques were followed from Manning (2002b) as well as from personal advice and guidance from Dr N. Neave (University of Northumbria) and Dr R. Drewett (Durham University).

Suggestions for possible extensions of this current investigation

A number of improvements have already been suggested in the previous section, to resolve possible limitations and weaknesses of this current study. Possible future extensions will now be suggested.

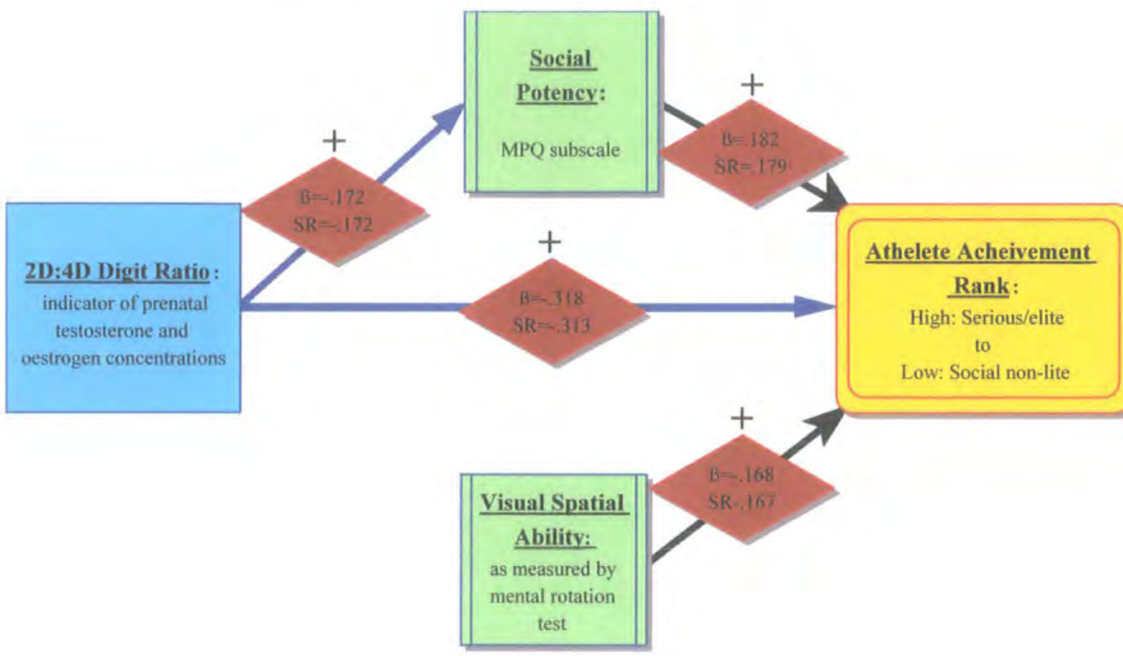
This current investigation examined various physical, mental and psychological variables thought to influence achievement rank, across different sports of varying contact intensity. It would, however, be interesting to apply the same format to investigate systematic variations within a single sport. There is considerable diversity with regards to the different positional requirements within some team sports in terms of physical, mental and psychological traits. It would be particularly interesting to investigate the profiles associated with excellence in different field positions in popular team sports such as football and rugby, using digit ratio, mental rotation and specific personality variables (such as anxiety, arousal and sensation seeking). It would be predicted that uniquely different demands would be made upon, for example, a goal keeper (whose primary aim is to save goals) and a striker (whose primary aim is to score goals) in football. Similarly in rugby, different traits would be expected to characterise a successful front row forward (who is primarily concerned with scrummaging, rucking and malling) in comparison to a fly half (whose key positional role is primarily that of decision maker, and kicker). It would be equally informative to investigate the extent to which some variables remain constant over sport positions within a specific sport in regards to achievement rank; the commonalities to success among all positions within a team. Taken together these twin lines of research might allow the possibility of formulating 'ideal positional profiles' as a guide to achieving high rank in a specific position, as well as the formulation of 'ideal sport profiles' common to all positions within a sport. These profiles would be extremely useful for the successful structuring of group and individual training sessions for sports teams.

Conclusion

To conclude this study, I will present a brief overall summary of the investigation followed by an amended version of the proposed model presented at the start of the introduction. It has been amended in line with the findings of this current study.

This study aimed to investigate the influence of specific (testosterone-mediated) predictor variables upon the 'athlete achievement rank' of team sport participants, while also observing the moderating influences of the participants' sex and the contact intensity of their sport on these variables. Low ranking players (social/non-elite) were compared with high-ranking players (serious/elite) as were comparisons made between the combined sports players with a non-sports playing control group. Another major aim was to test a proposed model, that the relationship between digit ratio and achievement rank is mediated by mental rotation ability and the psychological variables: social potency, achievement, harm avoidance and control. As expected 2D: 4D digit ratio was found to be a significant discriminator of athlete achievement rank, and participant sex, as was the personality variable social potency. A novel finding was that digit ratio was significantly associated with achievement rank for the female sports participants. The other personality variables were found to have poor predictive validity, possibly due to a lack of specificity within a sporting context. The physiological variables of participant weight and height were also found to be significantly correlated with rank and unsurprisingly sex. However, of all the variables measured, the secondary variables: 'years spent playing' and 'hours spent training/playing per week' were both separately found to be associated with more variance in athlete achievement rank than any of the other variables including the primary predictor variable digit ratio. Mental rotation ability was unexpectedly and unaccountably found to be negatively correlated with achievement rank (opposite to hypothesised). Multiple regression analysis revealed that digit ratio's influence upon athlete achievement rank was highly independent of the influence of the other predictor variables with years played and hours trained/played per week found to have the greatest moderating influence on this effect. No significant differences in the predictor variable scores were found between sports participants of different contact intensity. Other than for digit ratio, the non-sport participants were not found to be heterogeneous from the sport participants, indicating that it is likely to be the occurrence of environmental influences, which initiates sport participation. This current investigation therefore concludes that low 2D: 4D digit ratio and high extroversion, assertiveness and dominance (as subsumed by social potency) are indeed importantly associated with success and achievement in team sports of varying contact intensity, as is an individual's physiological predisposition/suitability to their sport. However the most important influence on team sports achievement was found to be the longevity and intensity of playing and training in their sport, thought to be due to the increased skill acquisition associated with this. Ethical considerations were made regarding the sole use of digit ratio for player recruitment and for 'player poaching' purposes, as were improvements suggested regarding a need to regulate further the participant testing circumstances. Suggestions for further research were made regarding using the current design to investigate positional variation and similarities within team sports, of variables associated with athlete achievement rank. It appears then, that for male and female team sport participants, no matter how well genetically and physically they are suited to their sport, if they don't play regularly and train intensely, they are likely not to achieve the highest standard!

Figure 4:
Amended model of proposed influences of predictor variables and their relative interactions on athlete achievement rank with the relevant Beta (β) and Semi partial (SR) values for each interaction included



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Appendices

Appendix 1: Sample copy of verbal participant briefing

Appendix 2: Sample copy of participant consent form

Appendix 3: Sample copy of mental rotation test (Philips & Rawles, 1976)

Appendix 4: Sample copy of participant information sheet

Appendix 5: Sample copy of personality inventory

Appendix 6: Sample copy of research findings and conclusion sheet

Appendix 7: Sample copy of hand photocopy with 2D: 4D digit ratio measurements and calculations

Appendix 1

Sample copy of verbal participant briefing

Information about the current study

This study aims to investigate the relative contributions and the interactive influences of a number of variables upon athlete achievement rank (the level you play at) in team sports. These variables include 2D: 4D digit ratio, specific personality variables and mental rotation ability. The possible moderating influences of participant sex and sport contact intensity upon these relationships will also be investigated. Finally in this study the variable scores of the sports participants will be compared to those of a non-sport participant control group. 2D: 4D digit ratio is the ratio between the length of the index (2nd) finger and the ring (4^{th}) finger, taken in this study from your right hand, which I will later measure from photocopies. It is considered a physiological marker of prenatal testosterone and oestrogen and consequently also considered a predictor of rank in sports. I will see if this measurement in anyway predicts your achievement rank in team sports, of varying contact intensity (basketball, football and rugby). I will also see if this is related to personality (by administering a personality questionnaire) and to visual spatial ability (as measured by a mental rotation test) both of which have also been previously reported to be influenced by prenatal testosterone and oestrogen and to have influences themselves upon achievement rank in team sport athletes. I will also see if any noticeable sex differences occur for any of the interactions.

All participants' results will be strictly confidential, which is why I will ask you to seal your test documents in the envelopes provided immediately on test completion. All results will immediately be coded to numbers instead of names, so no possible accidental release of personal information will occur and personal information, in no case, will be revealed to anyone other than your selves personally on request. You will be sent a 'research findings and conclusions sheet' on conclusion of this study.

Please note that you are free to withdraw from this study at any time, without need for reason.

If you have any questions regarding this current study please do not hesitate to ask me either before or after the testing. If at a later date you have any questions, my email address is: nicholastester@hotmail.com

Thank you for your participation

With regards

Nicholas Keith Tester

Appendix 2

Sample copy of participant consent form

CONSENT FORM

Mediating variables in the relationship between 2D: 4D digit ratio and sports achievement rank

Approved by Durham University's Ethics Advisory Committee

(The participant should complete the whole of this sheet himself/herself)

Please cross out as necessary

Have you read the Participant Information Sheet? YES / NO

Have you had an opportunity to ask questions and to discuss the study? YES / NO

Have you received satisfactory answers to all of your questions? YES / NO

Have you received enough information about the study? YES / NO

Who have you spoken to? Dr/Mr/Mrs/Ms/Prof. ....

Do you consent to participate in the study? YES/NO

Do you understand that you are free to withdraw from the study:

* at any time and
* without having to give a reason for withdrawing and
* without affecting your position in the University? YES / NO

Signed ....

Date ....

(NAME IN BLOCK LETTERS)

....

Appendix 3

Sample copy of mental rotation test (Philips & Rawles, 1976)

Important.
Do not open this booklet until you are told.

Name.

Sex.

Age.

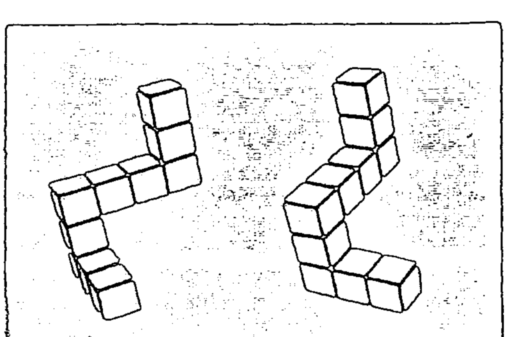
Occupation.

~~6101~~

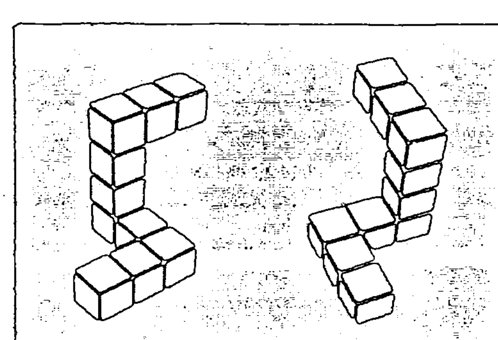
S & M Test

Look at each pair of pictures and decide whether they are two pictures of the same object, or two different objects. Put a tick against the appropriate word. Work as fast as you can without making mistakes.

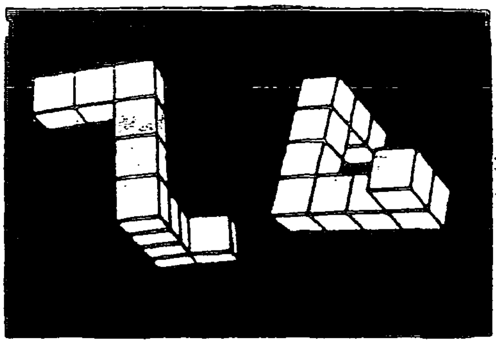
Examples.



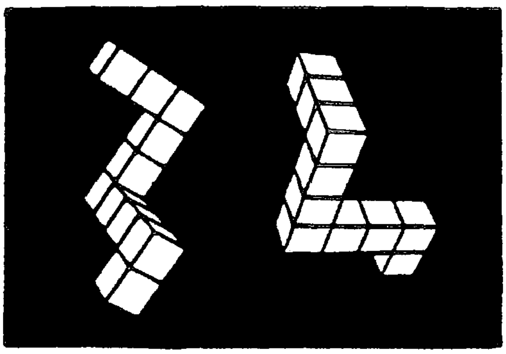
Same ☑ Different ☐



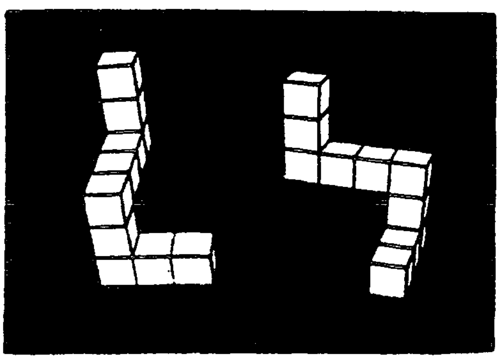
Same ☐ Different ☑



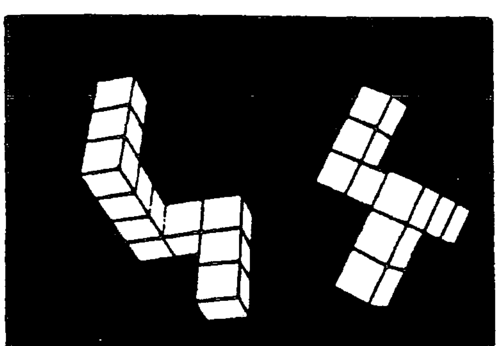
11 Same ☐ Different ☐



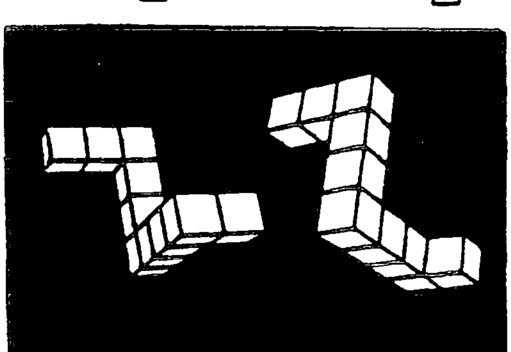
12 Same ☐ Different ☐



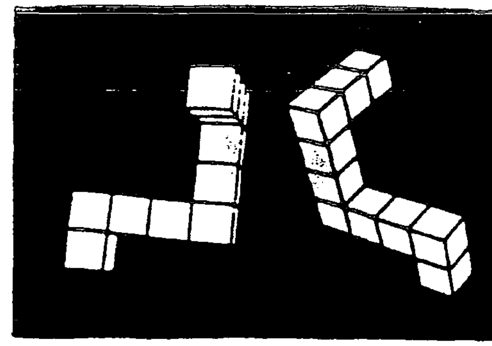
13 Same ☐ Different ☐



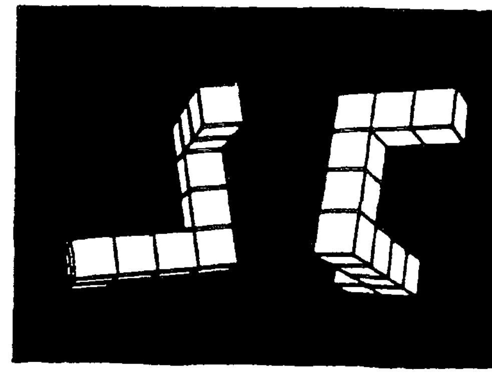
14 Same ☐ Different ☐



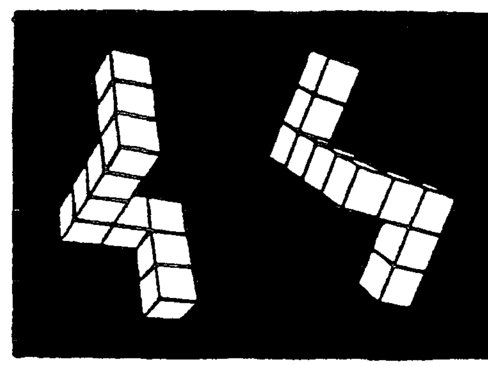
15 Same ☐ Different ☐



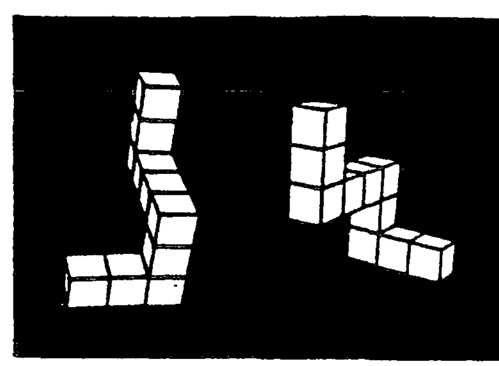
16 Same ☐ Different ☐



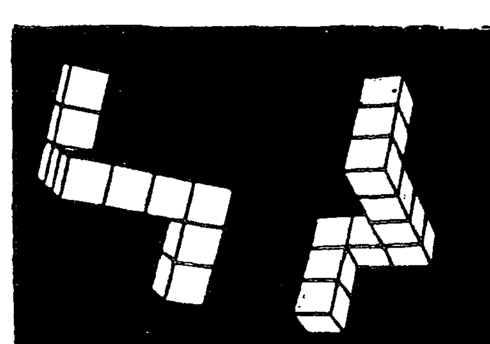
17 Same ☐ Different ☐



18 Same ☐ Different ☐



19 Same ☐ Different ☐



20 Same ☐ Different ☐

Appendix 4

Sample copy of participant information sheet

Sports Participation Information sheet

You do not have to give your name and all information you provide is completely confidential.

Name: ----------------------------
Ethnic Origin: Mother-----------------------Father-----------------------
Age: -------(years and months)
Height: ---------(cm/feet)
Weight: ---------kg/stone)
Main sport: -------------------
No. of years spent participating in this sport: ----------
No. of hours spent training/playing per week (please tick relevant box):

[_] None
[_] 0-3 [_] 12-15
[_] 3-6 [_] 15-18
[_] 6-9 [_] 18+
[_] 9-12

Have you suffered any serious injuries in the past to any of your fingers on your right hand (except your thumb), if so, please give details:-----------
----

Please choose your most suitable rank for your sporting activity by circling the most suitable number. Start from rank 10 and work down.

Rank	Criteria
10	You have represented your country
9	You think you could represent your country
8	You have competed at national level
7	You think you could compete at national level
6	You have competed at county level
5	You think you could compete at county level
4	You have competed at an organised level
3	You think you could compete at an organised level
2	Your sport is only social
1	You do no sport

Appendix 5

Sample copy of personality inventory

Participant Questionnaire

Instructions:

In this booklet you will find a series of statements a person might use to describe her/his attitudes, opinions, interests and other characteristics. Each statement is followed by two choices, lettered (a) and (b) in the booklet. Read the statement and decide which choice best describes you. Then underline your letter of choice clearly with a pen in the booklet. Please answer every statement, even if you are not completely sure of the answer. Read each answer carefully, but don't spend too much time deciding on the answer.

I enjoy being in the spotlight.
(a) True, (b) False.

Some people say that I put my work ahead of too many other things.
(a) True, (b) False.

Of the following two situations I would like least:
(a) Having to walk around all day on a blistered foot.
(b) Sleeping out on a camping trip in an area where there are rattle snakes.

I am more likely to be fast and careless than to be slow and plodding.
(a) True, (b) False.

On most social occasions I like to have someone else take the lead.
(a) True, (b) False.

I am not a terribly ambitious person.
(a) True, (b) False.

Of the two situations I would like least:
(a) Being chosen as the "target" for the target of a knife throwing act.
(b) Being sick too my stomach for 24 hours.

I almost never do anything reckless.
(a) True, (b) False.

I do not like to be the centre of attention on social occasions.
(a) True, (b) False.

I push myself to my limits.
(a) True, (b) False.

Of the following two situations, I would like the least:
(a) Having a pilot announce that the plane has engine trouble and may have to make an emergency landing.
(b) Working the fields digging potatoes.

I am a cautious person.
(a) True, (b) False.

On social occasions I usually allow others to dominate the conversation.
(a) True, (b) False.

I enjoy putting in long hours.
(a) True, (b) False.

Of the following two situations, I would like the least:
(a) Being at the circus when two lions suddenly get loose down in the ring.
(b) Bringing my whole family to the circus and then not being able to get in because a clerk sold me tickets for the wrong night.

I often prefer to "play things by ear" rather than to plan ahead.
(a) True, (b) False.

I perform for an audience whenever I can.
(a) True, (b) False.

I like hard work.
(a) True, (b) False.

Of the following two situations, I would like the least:
(a) Being seasick every day for a week while on an ocean voyage.
(b) Having to stand on the ledge of the 25th floor of a hotel because there's a fire in my room.

I don't like to start a project until I know exactly how to proceed.
(a) True, (b) False.

When I work with others, I like to take charge.
(a) True, (b) False.

I like to try difficult things.
(a) True, (b) False.

It might be fun and exiting to experience an earthquake.
(a) True, (b) False.

I generally do not like to have detailed plans.
(a) True, (b) False.

I do not like to organise other people's activities.
(a) True, (b) False.

I set extremely high standards for myself in my work.
(a) True, (b) False.

Of the following two situations I would like least:
(a) Being out on a sailboat during a great storm at sea.
(b) Having to stay home every night for two weeks with a sick relative.

I like to stop and think things over before I do them.
(a) True, (b) False.

I usually do not like to be a "follower".
(a) True, (b) False.

I often keep working on a problem, even if I am very tired.
(a) True, (b) False.

Of the following two situations I would like least:
(a) Being in a flood.
(b) Carrying a ton of coal from the backyard into the basement.

I often act on the spur of the moment.
(a) True, (b) False.

I am quite effective at talking people into things.
(a) True, (b) False.

I often go on working on a problem long after others would have given up.
(a) True, (b) False.

I might enjoy riding in an open elevator to the top of a tall building under construction.
(a) True, (b) False.

I would enjoy trying to cross the ocean in a small but sea worthy sailboat.
(a) True, (b) False.

I am very good at influencing people.
(a) True, (b) False.

I find it really hard to give up on a project when it proves too difficult.
(a) True, (b) False.

Of the following two situations, I would like least:
(a) Riding a long stretch of rapids in a canoe.
(b) Waiting for someone who's late.

I often act without thinking.
(a) True, (b) False.

I am quite good at convincing others to see things my way.
(a) True, (b) False.

People say that I drive my self to hard.
(a) True, (b) False.

It might be fun learning to walk a tight rope.
(a) True, (b) False.

I am very level-headed and always like to keep my feet on the ground.
(a) True, (b) False.

I don't enjoy trying to convince people of something.
(a) True, (b) False.

I work just hard enough to get by without overdoing it.
(a) True, (b) False.

I usually make up my mind through careful reasoning.
(a) True, (b) False.

People consider me forceful.
(a) True, (b) False.

When faced with a decision I usually take time to consider and weigh all aspects.
(a) True, (b) False.

When it's time to make decisions, others usually turn to me.
(a) True, (b) False.

Before I get into a new situation, I like to find out what to expect from it.
(a) True, (b) False.

Appendix 6

Sample copy of research findings and conclusion sheet

Mediating variables in the relationship between 2D: 4D digit ratio and athlete achievement rank

Research findings

A summary of the findings of this current investigation, is as follow:

- Both 2D: 4D digit ratio and the personality variable of 'social-potency' were found to be significant discriminators of sports participants' athlete achievement rank as well as their sex.

- Sport participants' 'height' and 'weight' measures were also found to be significant discriminators of their athlete achievement rank and sex.

- Lower rank sport participants were surprisingly found to have significantly better scores on the mental rotation task than the higher rank sport participants.

- The non-sports participants' were only found to significantly differ from the sports participants on digit ratio (higher) and weight (lighter) of all the measured variables.

- Sport contact intensity and the personality variables 'achievement', 'control' and 'harm-avoidance' were all found to have poor predictive validity within this study.

- Statistical analysis revealed the influence of 2D: 4D digit ratio upon athlete achievement rank to be highly independent of the other 'predictor variables' (mental rotation and personality variables).

- Of all the variables measured, the best predictors of athlete achievement rank were found to be the 'the years participants had played' and their 'time spent training/playing per week' indicating the importance of these variables above others for achieving high rank in team-sports. These two variables were also found to have the greatest combined mediating influence on 2D: 4D digit ratio's correlation with athlete achievement rank.

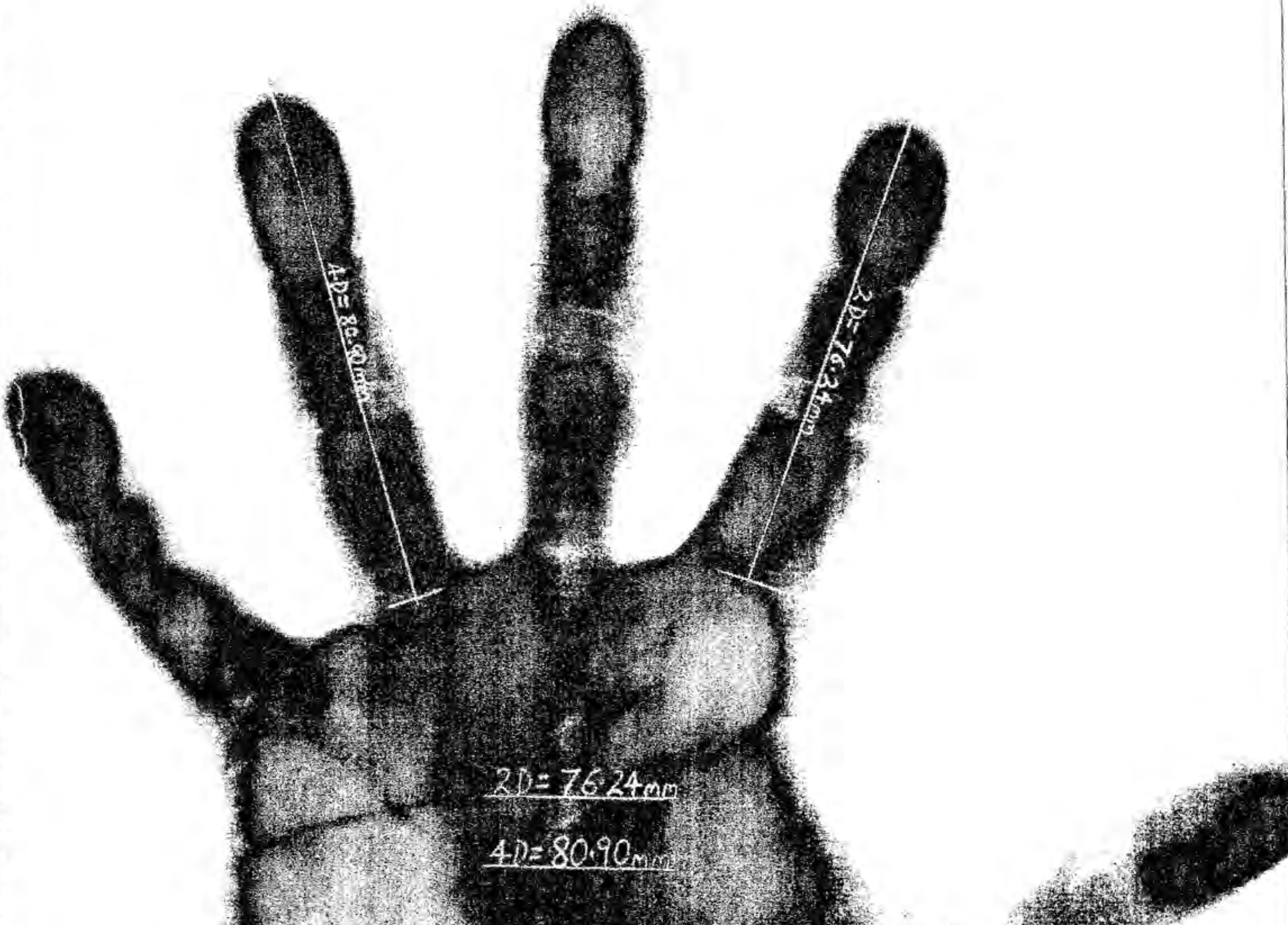
Thank you again for you participation. If you have any further questions, do not hesitate to contact me on:
nicholastester@hotmail.com

With regards

Nicholas Keith Tester

Appendix 7

Sample copy of hand photocopy with 2D: 4D digit ratio measurements and calculations


2D= 76.24mm
4D= 80.90mm
2D:4D= 0.9424