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THE VALIDITY OF A NON-INVASIVE METHOD OF MATURITY ESTIMATION AND INTRINSIC RISK FACTORS FOR INJURY IN YOUTH FOOTBALL PLAYERS: ANALYSIS OF THE 2002 AND 2003 SEASONS

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THE VALIDITY OF A NON-INVASIVE METHOD OF MATURITY ESTIMATION AND INTRINSIC RISK FACTORS FOR INJURY IN YOUTH FOOTBALL PLAYERS: ANALYSIS OF THE 2002 AND 2003 SEASONS

By

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ABSTRACT

THE VALIDITY OF A NON-INVASIVE METHOD OF MATURITY ESTIMATION AND INTRINSIC RISK FACTORS FOR INJURY IN YOUTH FOOTBALL PLAYERS: ANALYSIS OF THE 2002 AND 2003 SEASONS

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Youth participation in tackle football is increasing each year. Late maturation has been implicated as a risk factor for injury. Percentage of predicted adult stature derived from the Khamis and Roche [KR](1994) non-invasive method of adult stature prediction has been proposed as an alternative to invasive measures of maturity. Percentage of predicted adult stature remains untested as a maturity indicator in youth football players. The purpose of this study was to determine the validity of percent of predicted adult stature in youth football players, and to examine maturity as a risk factor for injury in the same population. There were 779 youth football players in grades fourth through eighth involved in the injury analysis study and a subset of 64 participated in the validation of the non-invasive method of maturity estimation. Partial correlations controlling for chronological age revealed that the KR percent of predicted adult stature was moderately, but significantly related to skeletal age (partial r, adjusted for CA, = 0.54; $p < .001$). Injury analysis revealed that 284 players accounted for 474 injuries and 26565 exposures. Players were twice more likely to be injured in games than in practices and 1.4 times more likely to suffer a non-time-loss injury. Risk factor analysis revealed that maturity was not a risk factor for injury. Stature and previous injury were significant risk factors for injury.

This dissertation is dedicated to my father who always told me to get a college degree; he just never told me when I could stop.

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Chapter One

Introduction

Participation in organized sports is an increasingly popular form of recreational activity for children. One sport that is growing in popularity is American football. Over 2.8 million persons over the age of six participate in tackle football each year (Sporting Goods Manufacturers Association, 2004). Two of the largest youth football organizations, Pop Warner Little Scholars [PW] (2003) and American Youth Football [AYF] (2004), boast over 240,000 and 200,000 annual participants respectively. Many other local, regional and state organizations exist making the total number of participants much higher.

The National Safe Kids Campaign [NSKC] (2004) reports that more than 3.5 million children between the ages of 5 and 14 are injured while participating in sports each year. Of those 3.5 million, large proportions were seen in hospital emergency rooms. Of those visits, 207,400 were attributed to basketball, 187,800 to football, 116,900 to baseball and softball, 76,200 to soccer, and 21,200 were attributed to gymnastics. The NSKC also reports that 28 percent of youth football players between the ages of 5 and 14 were hurt while playing their sport. While emergency room visits are important when considering the burden of injury on society, it does not take into account the numerous injuries that occur but are not treated in emergency rooms. Powell and Dompier (2004) found that only 25 percent of the injuries reported by college football players warranted medical attention or time loss from participation. If these proportions are similar in youth football, then the actual number of children injured playing youth football is much higher than previously reported. The relative increase in injury incidence in youth sports, and the increased publicity of injured professional and collegiate athletes, has heightened interest in the risk and prevention of injury among youth football players.

Injury is an inevitable part of sport, but some proportion is probably preventable. Adirim and Cheng (2003) describe a general injury prevention model that identifies the "three E's", educational, environmental, and enforcement interventions. In the context of youth football, education includes the mastering of football techniques and proper training for coaches. Environmental interventions include the type or condition of the playing surface, temperature conditions, or inclement weather policies. Lastly, enforcement involves coaches following policies and procedures and officials enforcing the rules and equipment standards. Hergenroeder (1998) further proposed six areas of injury prevention, including preseason physicals, medical coverage at practices and events, coach education, proper hydration, proper equipment and field maintenance, and proper rule enforcement and modification. As technology and knowledge advances, the properties of protective equipment improve and rule modifications must take place to accommodate new products. To monitor the effects that changes to equipment or rules have on sport, injury surveillance is used to identify and analyze the associations of risk factors and or the efficacy of interventions.

Injury patterns in high school and collegiate football have been described, but there remains a severe paucity in the literature describing injury patterns in youth football (14 years of age and under). The major reason for this difference is the organizational structure at lower levels of competition. High school and college athletic conferences have league and or national injury surveillance programs to monitor injury patterns over time. The advantage that high schools and colleges have over youth sports organizations is the availability of trained medical professionals to document injury and exposure information. Youth sports generally do not have the organizational structure, personnel, or finances to conduct injury surveillance programs. The coaches and league officials, although generous with time and effort, rarely have formal training in coaching or injury prevention and are typically volunteers. This lack of formal training limits the majority of available injury data regarding youth football to hospital registries, retrospective surveys, or coach reports. Research examining specific risk factors for injury in youth football is even more limited and is further complicated by the nonlinear growth of adolescents as they progress through maturity.

Maturity is the process of progressing to the mature state of adulthood (Malina, Bouchard and Bar-Or, 2004). Maturity status can vary greatly among individuals of the same sex and within the same age group. Variations are also dependent on the biologic system that is considered. The three most commonly considered systems are the skeletal, sexual and somatic systems. These three systems are related, but the status obtained from each can differ significantly from a child's chronological age and from each of the other systems. The disparity is most notable during the years surrounding puberty and the onset of the adolescent growth spurt (9-11 for females and 10-12 for males).

The methods of assessing skeletal, secondary sexual characteristics, and somatic maturity have strengths and weaknesses. Skeletal maturity measured from radiographs is considered one of the most accurate methods of assessing biologic maturity (Bayley, 1946; Groell, Lindbichler, Riepl, Gherra, Roposch, and Fotter, 1999; Roche and Davila, 1976; Roche, Davila, and Eyman, 1971; Tanner, 1962). This method can be used throughout all periods of growth, but is costly, invasive, and exposes the subject to radiation. Secondary sexual characteristics such as pubic hair development, the age at menarche, testicular volume, and breast development have also been used to determine sexual maturation. These processes are invasive and can be embarrassing for adolescents, and are further limited to a small time period surrounding the ages of puberty. The method of assessing secondary sexual characteristics is the most widely used measure in clinical studies, and has been shown to be reliable (Bonat, Pathomvanich, Keil, Field, and Yanovski, 2002; Brooksgunn, Warren, Rosso, and Gargiulo, 1987; Demirjian, Buschang, Tanguay, and Patterson, 1985; Matsudo and Matsudo, 1994; Schlossberger, Turner, and Irwin, 1992; Taylor, Whincup, Hindmarsh, Lampe, Odoki, et al., 2001; Tanner, 1962). There are two common methods of assessing somatic maturity. The first requires longitudinal data from which the onset of the adolescent growth spurt and peak height velocity (PHV) is derived. This method however, is limited by the need for longitudinal data and a narrow period during which it is useful. Bayer and Bayley (1959) described a method of somatic maturity estimation that expresses a child's current stature as the percentage of their predicted adult stature (PPAS). Other methods of estimating somatic maturity include taking other various anthropometric measurements, but PPAS is regarded as the most versatile (Malina et al, 2004a).

Estimating a child's PPAS is applicable to a variety of study designs and can be used across a wide range of age groups. To determine a child's PPAS, the child's predicted adult stature (PAS) must first be calculated. There are various methods to estimate PAS, but most require the child's current chronological age (CA), stature, weight, skeletal age (SA), and mid parent stature (MPS). More recently, Khamis and Roche (1994) developed a non-invasive method that does not require SA. The PPAS can be used to estimate maturity because two children who are the same stature and age may differ because one has already attained a greater percentage of predicted adult stature. This method offers several advantages. First, it is easy to perform on large samples and can be conducted at a time convenient to the individual, team, and investigators. Secondly, the equipment requirements are minimal. Lastly, this method is non-invasive and inexpensive making it practical for a variety of study designs.

Few studies have examined maturity as a risk factor for injury in youth football, yet it has been argued that children should be matched based on maturity rather than chronological age, ability, or grade in school (Baxter-Jones, 1995; Caine & Broekholl, 1987; Gallagher, 1969; Goldberg & Boiardo, 1984; Hafner, Scott, Veras, Goldberg, Rosenthal, Robertson, and Nicholas, 1988; Kreipe, 1985). This argument is centered on whether or not a child who is less mature is at risk for injury if playing football with other children of the same age who are more mature. Many systems currently exist for matching children for competition. These include CA, sex, skill level, weight, and biologic maturity (often measured in the form of sexual maturity). Pop Warner developed a classification matrix based on statures and weights rather than age or grade level. The AYF Organization classifies children according to grade level for tackle football and by age for touch and flag football. The Mid-Michigan Pony Football League (the focus of the current study) classifies children by grade, but has further restrictions that are based on birth dates. The most commonly used criteria are CA, grade in school, and sex. These criteria are most often disputed around the age of puberty when sex differences in timing and tempo of maturation can have a significant effect on skill, strength, fitness, and size (Beunen, Ostyn, Simons, Renson, & van Gerven, 1980; Katzmarzyk, Malina, and Beunen, 1997; Mota, Guerra, Leandro, Pinto, Ribiero et al., 2002; Pratt, 1989; Rarick and Oyster, 1964). Three studies that have examined maturity as a risk factor for injury in youth football are inconclusive (Linder, Towsend, Jones, Balkcom, & Anthony, 1995; Malina, Morano, Barron, Miller, and Cumming, 2002; Violette, 1976).

Research on the relationship of maturity and youth football injury is sparse. There have been three studies to date that have examined maturity as a risk factor for injury in youth football. Linder, et al. (1995) speculated that junior high school football players who were more mature were at greater risk for injury. To determine this relationship, the authors used the stages of secondary sex characteristics described by Tanner (1962) to determine maturity status. A physician provided these evaluations at the time of their preparticipation physicals. Players with higher levels of maturity were found to be at greater risk of injury. In the second study, Malina, Morano, et al. (2002) reported no relationship between injury risk and maturity in a group of youth football players. Lastly, Violette (1976) studied stages of secondary sexual characteristics in middle and high school football players, and found that amongst the younger age groups, those less mature were at greater risk of injury. This disparity among the few available studies makes it impossible to determine if matching children by maturity is an effective means of reducing injury risk in youth football players. Opponents of matching by maturity versus age cite that removing children from peer groups and placing them on teams with older or younger children may have profound effects on the child's self-esteem and or self-concept (Baxter-Jones, 1995). To further investigate the efficacy of matching youth football players by maturity, a valid method of estimating maturity most be found.

Purpose of the Study

The recent advent of the Khamis and Roche [KR] (1994) method for estimating PAS in absence of skeletal age (SA) provides a practical method for classifying children by PPAS in a variety of study designs. Although the KR method has shown to have little increase in error when compared to its correlate that includes SA, it remains untested in a sample of youth football players. Youth football players may differ significantly from the reference population from which these regression coefficients were derived. Participants in sports such as football are prone to selection bias because characteristics such as size, strength and speed are considered essential for success. Thus, this method should be applied and validated in a sample of youth football players to determine if it is a valid method of differentiating maturity status in a selection-biased sample.

Speculation exists that maturity is a risk factor for injury and that competition levels should be arranged according to maturity status versus age or grade level. Few studies have considered maturity as a risk factor for injury in youth football. The purpose of this study is to determine the validity of PPAS when derived from the non-invasive KR method of predicting adult stature, and to use these estimates in an injury risk model.

Hypotheses

This study has two facets that will be examined. The first facet is to assess the efficacy of the KR method for predicting adult stature. and to determine the validity of

PPAS as an estimate of maturity. This comparison will be accomplished by comparing the KR method to the Roche, Wainer, & Thissen [RWT] (1975) method of PAS that was updated by Khamis and Guo [RWT-KG] (1993). The RWT-KG method is generally considered superior to the KR method because of the inclusion of SA (Khamis & Guo, 1993), but the KR method (derived from the same sample) has been shown to have little increase in the 90% error bounds (Khamis & Roche, 1994). The second Stage of the study will involve the analysis of injury risk, rates and risk factors. Maturity status has not been adequately studied as a risk factor for injury in youth football and will be analyzed in relation to other intrinsic player variables and injury using univariate and logistic regression methods. The specific research questions and corresponding null hypotheses that were examined include:

1. Is the KR method a valid estimator of predicted adult stature?

   $H_0 1$: No linear relationship exists between the predicted adult statures derived from the KR and RWT methods.

2. Is KR method of predicted adult stature a valid measure of maturity when expressed as a percentage of the predicted adult stature?

   $H_0 2$: No linear relationship exists between PPAS derived with the KR method and skeletal age.

3. Is maturity a risk factor for injury in youth football players?

   $H_0 3$: No relationship exists between maturity status and injury.

Research Design

Two study designs were utilized to examine the research questions. The first Stage consisted of a cross-sectional design, and the second consisted of an observational cohort design. The cohort consisted of youth football players in the fourth through eighth grades (8.5-14.5 years old) that were observed over two years in two central Michigan communities that participate in the Mid-Michigan Pony Football League.

Limitations

Reported injuries are limited to those that were reported to the onsite investigator. Some injuries may not have been brought to the attention of the investigator. The samples in both stages are convenience samples. All youth football players who are registered participants on one of the two teams, and their parents who complete the necessary informed consents were included in the respective sample. The samples may not be representative of other youth football players in the State of Michigan.

Delimitations

The sample population selected for this study is limited to youth football players in two central Michigan communities in the 2002 and 2003 football seasons. The ability to generalize to all youth football players beyond those of similar communities in central Michigan is limited. The sample does represent the suburban nature of central Michigan and can be generalized to similar areas within the State.

Operational Definitions

This study uses a consistent set of definitions previously established by the National Athletic Injury Reporting System (NAIRS) (Powell, 1980) and reported elsewhere (Powell and Dompier, 2004).

Athlete exposure. Athlete exposures (AE) are defined as an opportunity for an athlete to be injured. Exposures are calculated by tallying the number of active participants in each coach directed session. Exposures are separated by session type and participation level for analysis purposes. Each player active in a session is counted as one exposure. Total daily exposures are the total number of active participants during that session. These are then totaled across participation levels for the total season exposures in games and practices.

Body mass index. Body mass index (BMI) is a measure of body weight relative to stature and is defined as weight in kilograms divided by the square of stature in meters.

Incidence. Incidence is used synonymously with frequency. It is the count of occurrences of injury that occurred during the study period.

Incidence density ratio. The incidence density ratio (IDR) is the proportion of two injury rates and provides a basis of comparison.

Injury definition. Time-loss (TL) injuries include all cases that require the athlete's removal from the current or subsequent sessions. Included are any suspected concussions requiring medical referral or observation prior to returning to play, dental injuries that require referral, any fracture, and any injury requiring medical evaluation. Non-time-loss (NTL) injuries include any athlete and investigator contact that requires evaluation and or treatment by the Certified Athletic Trainer (ATC) but does not require removal from the current or subsequent sessions.

Injury rate. The injury rate (IR) is the proportion of injuries that occur per 1000 AE. The IR is calculated by dividing the number of injuries by the number of AE.

Injury severity: Time-loss injuries are further broken down into minor, moderate and major injuries. Minor injuries are those that require seven or fewer days lost from participation. Moderate are those injuries that require eight to twenty days lost from participation, and major are those that require greater than twenty-one days lost participation.

Midparent stature. The midparent stature (MPS) is the average stature of the biological mother and father. The MPS was calculated by summing the statures of both biological parents and dividing by two.

Odd ratio. The odds ratio (OR) is the ratio of two odds. The OR is calculated with the following equation: (exposed cases * non-exposed non-cases)/(non-exposed cases * exposed non-cases).

Predicted adult stature. Predicted adult stature (PAS) is an estimate of the stature a subject will attain at the age of 18-years old. Predicted adult stature can be obtained by using any number of regression equations.

Percent predicted adult stature. The percent of predicted adult stature (PPAS) is a somatic measure of maturity. The child's current stature is expressed as a percentage of their PAS. Children of the same chronological age and stature can have attained various percentages of their adult stature, thus differentiating them from one another based on maturity.

Relative risk. The relative risk (RR) is a ratio between two risks. The RR is calculated with the following equation: (exposed cases * the total exposed)/(non-exposed cases * the total non-exposed).

Risk. Risk is the proportion of injured players among the total sample of players during the study period and is expressed per 100 players. It is the number of injured players divided by the number of players.

Session. Any coach directed practice or game.

Chapter Two

Literature Review

The purpose of this study was twofold. First, the validity of the Khamis and Roche (1994) method of estimating predicted adult stature, and subsequent percent of adult stature was examined in a group of youth football players in the Mid-Michigan Pony Football League. Secondly, maturity was assessed as an injury risk factor in the same population. In order to gain insights from previous research that has been conducted in the field of maturity assessment and injury risk, this review of literature was divided into five major sections: (1) Matching youth by maturity for sports participation, (2) Methods for assessing maturity status, (3) Injury incidence in football, (4) Risk factors for injury in football, and (5) Summary of the Literature. Special emphasis was placed on locating studies that included youth and junior high school football players.

Matching Youth by Maturity for Sports Participation

The biologic maturity of children and adolescents of the same chronological age (CA) can vary greatly. Chronological age can vary from biologic age or maturity status by four or more years (Jones, Hitchen, and Stratton, 2000; Katzmarzyk, et al., 1997; Malina, Bouchard, et al., 2004; Roche et al., 1975). This difference is even more apparent during adolescence around the time of puberty and the adolescent growth spurt. This period coincides with significant alterations in growth, body composition, cardiovascular endurance, and muscular strength (Malina, Bouchard, et al., 2004). For those reasons, matching youth in football by maturity status has been proposed as an alternative to matching by CA or grade in school (Baxter-Jones, 1995; Caine &

Broekhoff, 1987; Gallagher, 1969; Goldberg & Boiardo, 1984). There are three main reasons why matching by maturity was proposed: (1) Matching youth football players by maturity status was thought to make competition fairer and more satisfactory by allowing youth to participate against peers that are similar in size and strength, (2) Matching by maturity will reduce the age bias that is thought to exist because of age cutoff dates, and (3) Late maturing youth football players are thought at risk of injury when pitted against average and early maturity adolescents of the same CA.

Maturity and performance. There is a relationship between maturity status and performance parameters. In males, average and early maturing adolescents perform better in skill tests, are stronger, taller, and heavier. Conversely, females who are late maturing tend to perform better in some tasks, but are shorter and lighter than their more mature counterparts. These observations are sport specific and can vary due to many factors. Researchers have sought to determine if maturity and other personal characteristics such as CA, stature, and weight affect fitness parameters and performance.

The research examining maturity status and performance is consistent. Early studies examining skeletal maturity in males and females demonstrated that children who are advanced in maturity are also advanced in motor skill performance and strength (Rarick and Oyster, 1964). Similar results were reported by Katzmarzyk et al. (1997) using the Tanner-Whitehouse II method if SA assessment (Tanner, Whitehouse, Marshall, & Carter, 1975). Katzmarzyk et al. found similar results when analyzing the effect of maturity on strength and performance parameters in children between the ages of 7 and 12 years. Parameters included grip strength, pushing and pulling strength, a 35-yard dash, standing long jump, and a softball throw for distance. The combined effect of skeletal age (SA) and CA was the best predictor of motor performance while strength was best predicted by mass. The authors conceded the interaction of many parameters and note that performance and strength variables are dependent on many influencing factors and not exclusively on maturation or mass. Malina et al. (2000) found a performance advantage in elite soccer players who were advanced in maturity. Malina et al. used SA derived from the Fels Method described by Roche, Chumlea, and Thissen (1988). A similar effect has been noted in other studies that used other methods to estimate maturity.

An association between performance and maturity has been reported when secondary sexual characteristics were used to assess maturity. Jones, et al., (2000) examined maturity in relation to skill performance in a cross-sectional study of girls and boys between the ages of 10 and 16 years. The investigators measured multiple parameters, and maturity was graded by self-assessed sexual maturation. Sexual maturity was significantly and positively correlated to vertical jump, shuttle run, and grip strength scores in both boys and girls demonstrating a parallel relationship between increases in maturity and performance. Mota et al., (2002) found that maturity had an effect on running performance but not cardiorespiratory fitness. In another study examining running performance, Eisenmann and Malina (2003) studied age and sex associated variation in male and female distance runners. Males tended to increase task performance in most skills with concurrent increases in age, but females tend to plateau around the time of the adolescent growth spurt. This plateau effect has been demonstrated in other studies (Jones et al., 2000; Mota et al., 2002). A recent study by Malina, Eisenmann, Cumming, Ribeiro, and Aroso (2004) examined sexual maturity and performance in elite soccer players and found a large proportion of the variance in the performance parameters was related to maturity.

Maturity is an important factor that influences performance parameters and should be considered in research involving youth. This consistency in findings supports the assertion that children who are in the highest or lowest percentiles of maturity for a given age group should be considered for matching by maturity. Hafner et al., (1982) systematically matched athletes based on maturity and other player characteristics in an attempt to make competition fairer and more rewarding for middle and high school athletes. Adolescents who wished to be considered for moving up or down in competition level had to undergo a thorough evaluation of personal characteristics such as stature, weight, skill performance, and stage of sexual maturation. Throughout the season, data were recorded regarding playing status, injuries, success, and skill improvement. Outcome variables included athlete satisfaction, performance, and injury. Hafner et al. reported that the program of placement based on the listed criteria improved player satisfaction and competitiveness, but data regarding injury was regarded as unreliable and not adequately reported. Therefore, no inferences were made regarding player safety.

Age effect in sports. Age is another influencing factor thought to affect competitiveness in youth sports (Edwards, 1994; Simmons and Paull, 2001). Various sports have age cut-off-dates that dictate the level of competition a child will participate in and are solely based on the child's date of birth. Little League Baseball [LLB] (2004) is an example of a sport with a specific cut-off date. Little League Baseball has an age cut-off of 12-years-old and a year cut-off date of August 1st. A 12-year-old child born after August 1^{st} can play while a child who is born on August 1^{st} or before of the same year cannot play because they are too old. Youth football leagues use different classification criteria.

Youth football leagues have different criteria than little league baseball, and often differ from other youth football leagues. The PW (2004) youth football organization has developed an extensive age and weight chart that allows older participants of the specified weight to play at competition levels as many as three divisions lower. Conversely, a participant who is younger but much heavier can play on a level up to three divisions higher. The PW matrix was developed to equalize the competition levels, reduce size mismatches, and maximize development opportunities for the players (PW, 2004). The approach taken by the AYF (2004) organization is much different. The highest division within the AYF is only restricted to participants under the age of 16 years. The next division is comprised of 6^{th} to 8^{th} graders, and the lowest tackle football division is comprised of 3^{rd} to 5^{th} graders. Both the PW and AYF have flag football divisions that are determined solely by age. The Mid-Michigan Pony Football league (on which this study was based) has a different system of matching. There are four divisions, 4^{th} and 5^{th} grades are combined into one division, while the 6^{th}, 7^{th}, and 8^{th} grades each make up separate divisions. Players who are 9 years of age on or before September 1^{st}, or in 4^{th} grade of the current year will play in the youngest division. Players who are 12 years old before September 1^{st} must play in the 6^{th} grade, and those who are 13, must play in the 7^{th} grade. Players who are 14 years old must play in the 8^{th} grade. Potential players who are 15 years old before September 1^{st} are not permitted to play. These classification systems were designed with the best intentions of making competition fair and providing a safe environment for the athletes.

Few studies have examined the age effect in American football, and none have examined the possible age effect among youth football players. Daniel and Janssen (1987) surveyed professional football players in the Canadian Football League (CFL) and National Football League (NFL) and found no age effect among the players. In that study, 49% of the players in the CFL and 52% of the players in the NFL were born in the first half of the competition year. In a review of birth dates among 167 NFL Hall of Fame members, Stanaway and Hines (1995) also failed to find an age effect. That study reported 57% of those included were born in the first half of the competition year. Glamser and Marciani (1992) found an age effect among college football players at two universities. They found that 66% of the respondents were born in the first half of the competition year. The inconsistencies and paucity of literature surrounding the age effect in football makes forming any conclusions impossible. Other sports such as baseball, soccer and hockey have been more widely studied for age effect.

The age effect bias has been studied more extensively in sports such as baseball, soccer, and hockey. Most sports with the exception of baseball show an age effect. Two studies of baseball player birth dates revealed no age effect (Stanaway & Hines, 1995; Thompson, Barnsley & Stebelsky, 1991). Studies involving soccer players have included adult and youth, both at elite and at non-elite levels, and have all demonstrated that a birth effect does exist (Dudink, 1994; Maffulli, King, and Helms, 1994; Verhulst, 1992). Similarly, hockey has shown an age effect that has been widely reported (Daniel and Janssen, 1987; Hurley, Lior, and Tracze, 2001). It is unclear if the age affect is the result of athletes being born at the beginning of the competition season, or if it is from normal variation. If being born at the beginning of a competition year is advantage, than those who are earlier are at a competitive advantage over the younger members of their birth cohort.

Risk of injury in late maturing football players. Matching by maturity status has been proposed as a means of reducing injury risk in youth football. This recommendation, however, is based on speculation and intuition rather than research that demonstrates increased risk for less mature players. Three studies have examined maturity as a risk factor for injury in youth football. These studies report conflicting results further confounding the issue.

Only one of the three studies examining maturity in relation to injury risk found an increased injury risk in less mature players. Violette (1976) studied stages of sexual maturity and injury in middle through high school football players. Results demonstrate slightly greater risk of injury amongst the less mature in the 13, 14, and 15-year-old age groups, but no relationship was found in the 16 and 17 year old players. One of the weaknesses noted by the authors was the limited utility of sexual maturation in the 16 and 17-year-old age groups. Nearly all the participants in the higher ages were sexually mature or approaching sexual maturity. The index of sexual maturity may not have been sensitive enough in these age groups to detect a difference. The strength of this study was the prospective design, large sample, and thorough injury documentation. The other two studies examining this issue found an inverse or no relationship between maturity and injury risk in youth football players.

The two studies that failed to detect a positive relationship between maturity and injury risk in youth football players were biased by exposure time. Players who are heavier, taller, and stronger are likely to receive more individual playing time during games and more repetitions during practices making them more likely to suffer an injury. Linder et al., (1995) conducted a two-year prospective study of 340 junior high school football players between the ages of 11 and 15. There were 55 injuries reported during the duration of the study, and injury risk was higher in those athletes who were assessed as more mature. Exposure time was not recorded in that study. Malina, et al., (2002) reported no relationship between injury risk and maturity in a group of 9 to 14 year old youth football players. Malina et al. did note that injury risk increased with age and stature, but remained unrelated to maturity status. Team exposures were recorded, but individual playing time was not. Both studies were likely biased because the exposure definitions could not detect a difference between levels of maturity status. Children who are more mature were probably exposed more because they received more playing time.

Matching schemes for youth sports have been a source of much debate. The relationship between maturity and performance is well established, but the age effect bias is not clear in college and professional football and has not been studied in youth football. There are few studies that have examined maturity as a risk factor for injury in youth football players, and that have, are inconclusive. This disparity in the literature makes it impossible to determine which method of matching is most appropriate for providing a safe and fair competitive environment in youth football. Organizations such as PW have constructed complex matching schemes that make allowances for those children who are very small or large in relation to their CA peers, but others such as AYF continue to rely on matching by age and grade. The focus of the current study, the Mid-Michigan Pony League, uses grade and CA, but makes allowances for exceptionally large individuals to move up divisions. None of these organizations considers biologic maturity status assessed in any form as a component in the matching process. The difficulty associated with assessing maturity is the main reason that maturity assessments are not routinely conducted. It has been recommended that an assessment of maturity be conducted with every preparticipation physical exam (Caine and Broekhoff, 1987; Goldberg and Boiardo, 1984). Assuring consistent evaluation procedures amongst different doctors in different populations would be difficult. Alternative maturity assessment methods need to be explored.

Methods for Assessing Maturity Status

Maturity is a difficult concept to conceive and is often confused with the state of being mature. Maturity is the degree to which a person has progressed to a fully mature state or adulthood (Malina, Bouchard, et al., 2004). Maturation is the process of moving toward a mature state. Maturity is mistakenly considered as a total body process but should be considered separately for each biological system. Skeletal, somatic, and sexual maturity are related, but one or more of these processes will progress at a different rate than the others. In addition, biologic maturity does not coincide with CA. Children of the same sex and CA may differ greatly in their level of maturity. It is common for same sex children of the same CA to differ in biologic maturity by two or more years. The sex of the child is also important and inter-sex differences can be as high as four or more years of difference. Females, on average, are two years in advance of their male counter parts when nearing the age of puberty (9-11 for females and 10-12 for males). This sex, age and intersystem variability makes assessment of biologic maturity difficult, but nonetheless important.

The ability to estimate maturity is dependent upon the ability to measure progress of maturity at a given time (Malina, Bouchard, et al., 2004). Once this measure has been taken, criteria for assessing the level of maturity can be assigned for a specific sample. To assess maturity in youth athletes, the method must be applicable to the population of interest and practical for the restrictions of the study design. There are multiple methods of assessing maturity and each has strengths and weakness.

The common biological systems used to estimate biological maturity are the sexual, skeletal, and somatic systems. Sexual maturity is estimated using a number of different indicators. Secondary sex characteristics often include pubic hair development, testicular volume, breast development, and age at menarche. Skeletal maturity is estimated by determining a child's SA. Skeletal maturity is important because it can be measured during the entire growth period starting at birth and ending in young adulthood when growth is complete. The third most common method of assessing maturity involves anthropometric measurements. Several methods exist for estimating somatic maturity, but the most widely used is the age at take off (TO) and the age at PHV of the adolescent growth spurt. These measures, as with sexual maturation, are limited to the short time frame surrounding the event and require serial measurements. The less used somatic maturity measurement method is determining the PPAS a child has attained at a give age.

Secondary sex characteristics. Sexual maturation is the most widely used index of biologic maturity in the clinical and research settings. Sexual maturation is a process that ends shortly after the onset of puberty. Puberty is a period of transition between adolescence and adulthood (Malina, Bouchard, et al., 2004). Tanner (1962) described stages of secondary sexual characteristics development. These include pubic and axillary hair development, genital development, and breast development. Tanner defined five stages for each indicator. Stage five is fully mature while stage one indicates that the individual is pre-pubertal. Stages two, three, and four indicate that sexual maturity has begun but not yet finished and represent progressively increased development. This method has been widely used but has limitations.

The evaluation of secondary sexual characteristics can only be used at and around the ages of puberty (9-11 for females and 10-12 for males). Besides being limited to a short time frame around puberty, assessment of secondary sex characteristics is made difficult by the very nature of the evaluation. This form of evaluation by a clinician requires the adolescent to disrobe and the examiner having direct observation of the genitals, pubic area, and breasts. This procedure can embarrass some adolescents and can make them reluctant to participate. Allowing subjects to perform self-assessments can mitigate the invasive and embarrassing nature of the exam, but at a cost to sensitivity.

Two studies have reported good concordance between physician and subject self-assessment of secondary sexual characteristics. Duke, Litt, and Gross, (1980) provided females with five photographs each of breast and pubic hair development. Similarly, the males were provided with five photographs each of genital and pubic hair development. The subjects were instructed to select the photograph that best represented their own characteristics. These were then compared to physician ratings using the same photographs. The investigators report kappa coefficients of 0.81 for breast stage, 0.91 for

female pubic hair, and 0.88 for genital and male pubic hair development. Similarly, Matsudo and Matsudo (1994) compared the ability of subjects to perform a self-evaluation using Tanner (1962) stage photographs and mirror to that of a physician. Concordance for pubic hair was over 69%, and for breasts and genitals it was over 60%. This evidence is compelling, but other studies have failed to produce as high concordance.

Although physician assessment seems a reliable method of estimating sex characteristics, not all studies report good agreement between physician and subject assessment. Hergenroeder et al., (1999) conducted a study that not only examined physician and subject agreement, but also interobserver agreement between physicians. Participants were provided with drawings and written descriptions to aid in the self-assessment. The results demonstrated a 76% agreement rating between physicians, but kappa coefficients for physician subject agreement were poor (0.34-breast; 0.37-pubic hair). Similarly, Taylor et al., (2001) and Bonat et al., (2002) used simple drawn pictures based on Tanner's photographs but included simple text descriptions. Both studies found a low to moderate agreement between the physicians and subjects. The use of drawings in these studies versus the use of pictures used in the former studies may have made it more difficult for the subjects to determine stage. The inclusion of text descriptions did increase the accuracy of subject ratings.

Physician examination of secondary sexual characteristics, although a reliable method, is not always practical and decreases subject participation. Subject self-assessment can be used when physician assessment is unavailable. The studies that used actual copies of Tanner's photographs of stages of development produced better agreement. Those studies that used drawings and text descriptions were not as accurate. Matsudo and Matsudo (1994) recommended that if self-assessments must be used, then the subjects should be provided with color photographs, text descriptions, and a mirror to aid in the assessment process. There are situations however, when even self-assessment of secondary sex characteristics is not indicated and other methods must be sought. One such method that can be used in females is the age at menarche.

Age at menarche can be assessed separately or in conjunction with other sexual maturity indicators. In prospective and cross-sectional designs, questioning of the girls and their mothers is reliable in determining if the girl is pre or postmenarcheal. Retrospectively, women can be asked to recall their age at menarche with reasonable accuracy. Koprowski, Coates, and Bernstein (2001) reported a recall correlation of 0.83 in teenagers who were an average of 17 years old. Must et al., (2002) found similar findings ($r = 0.79$) in women asked to recall age at menarche in a 30-year follow-up study. A third method of estimating age at menarche is called the status quo method. This method provides a population estimate from the sample. Using the exact age of the adolescents and whether or not they have achieved menarche, an estimated percentage of girls who attained menarche in each age group can be derived (Malina, Bouchard et al., 2004). This method is not useful for application to individual females, but does provide an alternative if individual data are not available.

Skeletal age assessment. There are a number of reasons why SA age assessment might be performed. Clinically, SA assessments can be used to determine a child's present developmental status and to estimate or predict the adult stature of the child. Estimating adult stature is most often used when children and adolescents are thought to have a growth or endocrine disorder. From a research perspective, SA can be used to classify children according to maturity level. Numerous methods have been developed to assess SA from radiographs of various areas of the body including the hand, hip, knee and ankle. Methods utilizing the left hand have persisted because little radiation is required and the ease of positioning of the subject.

Each of the three common methods used to assess SA from left-hand radiographs have strengths and weaknesses. In the order of the most commonly used are the Greulich-Pyle [GP] (Greulich & Pyle, 1959), Tanner-Whitehouse [TW] (Tanner, 1962; Tanner et al., 1975; Tanner, Landt, Cameron, Carter, and Patel, 1983; Tanner et al., 2001), and the Fels methods (Roche et al. 1988). The GP and TW methods are the most commonly used by pediatricians and endocrinologists in the assessment of skeletal maturity. More recently, the Fels method has become popular in growth studies because it also provides a standard error of measure for the SA it estimates. All three methods provide regression equations for predicting adult stature using the skeletal age obtained from the radiograph.

The assessment of SA using the GP method has evolved from the early works of Todd (1937). In those early studies, anteroposterior radiographs of the left hand were examined for similarities in bone development based on age groups. The GP method was developed using the same radiographs obtained in Todd's original Brush Foundation Study conducted in Ohio between 1931 and 1942. Greulich and Pyle (1959) published a text on the assessment of skeletal radiographs in what is now called the "atlas". The atlas is the most commonly used method of clinical SA analysis in the United States (Zerin and Hernandez, 1991).

The GP method has comparisons and ratings for all 28 bones in the hand. To use the atlas, a current radiograph is compared to the pictures of radiographs in the atlas. This method is commonly applied incorrectly by comparing the current radiograph with a composite slide in the atlas. For example, if the x-ray of a 5-year old boy matches the slide of a 7-year old, then the boy's SA is 7-years. As described in the original text however, to correctly assess SA, the SA of each bone should be assessed and then divided by the total number of bones used in the analysis (Greulich and Pyle, 1959). Using the correct method, the SA might be assessed much differently from the incorrect method that estimated the age at 7-years. This method of visual comparison was thought very subjective and inaccurate by Tanner (1962), thus encouraging further research.

The subjectivity of the GP method was the basis for Tanner (1962) to develop a method that used written descriptions, ratings, and scores for each common criterion (bone description). This method included criteria for 20 bones in the left hand and wrist versus the entire hand used in the GP. The TW method defined specific criteria that had to be met in order for a bone to receive a particular rating that was then provided a score. The scores are then totaled and compared against a table that provides an estimated SA for a particular score. This method has been refined several times. The first revision called the TW2 Method was published 1975, and the most recent called the TW3 in 2001 (Tanner et al., 1975; Tanner et al., 2001). The TW2 and TW3 methods provide an alternative to the 20-bone (TW-20) method by providing scoring systems for just carpals and one for just long bones called the Radius Ulna Short Bone (RUS) method. The RUS method uses the radius, ulna and some of the metacarpals and phalanges, but no carpals. Throughout the revisions, the criteria were not changed, but the scoring system was changed. The TW method is commonly used by physicians due to the speed and ease of interpreting the radiographs, but has been criticized for subjectivity and lack of quantifiable measurements.

The Fels method is the newest method to assess SA. The Fels method was developed from serial radiographs collected during the Fels Longitudinal Study (Roche et al. 1988). This method uses 22 bones that may include up to seven additional indicators (bone descriptions) for each. The rating criteria provided for this method included written descriptions, pictures, and graphic examples. This method also uses quantifiable measurements to 0.5 millimeters for some indicators. The ratings for each indicator for a given age group are then entered into a computer program that calculates the SA and standard error of measurement (SE). This method is more difficult and time intensive to perform and not widely used by clinicians, but it is superior for research because it provides a SE with the SA.

Although the GP, TW, and Fels methods are commonly used, other methods of assessing SA have been developed for other locations on the body. One are that has been studied is the knee (Aicardi et al., 2000 Roche et al., 1975). Roche et al. (1975) developed a method for analysis of the knee, but later continued to focus on the left hand. In addition to the knee, hip and pelvis, attempts were made to assess SA age using radiographs of the foot, but none of these earlier methods have endured. Radiographic analysis of the left hand has remained popular because imaging of the hand allows for consistent positioning and it requires minimal radiological exposure. Positioning the foot, knee, hip and pelvis is much more difficult and the exposure to radiation has to be greater because of the thicker soft and bony tissue. Additionally, the bones of the hand

and wrist provide multiple indicators that have been repeatedly documented across the majority of the skeletal maturational period. For these reasons, SA assessment has and will continue to require the anteroposterior view of the left hand.

The GP, TW, and Fels methods are similar in that they all use the anteroposterior view of the left hand for SA analyses. Despite this similarity, they all have very different methods and reference populations. The reference population is an important consideration because each was derived from very different populations. The Brush Foundation Study that provided the sample for the GP method was conducted at Case Western Reserve in Northern Ohio with a sample of upper socioeconomic white children. The TW method was derived from a sample of the British population, and the Fels method used a sample from the Fels Longitudinal Study conducted in Southern Ohio with middle-income children. In a comparison of the GP and TW methods, Acheson, Vicinus, and Fowler (1966) found that the radiographs judged using the GP were about one year less on average than those same radiographs judged using the TW method. The investigators also found that interobserver error was smaller with the GP method, but that the confidence limits within a single reading were narrower with the TW method. Since that study the TW method has evolved twice into what is now called the TW3 method. More recently, the GP, TW, and Fels methods have been compared.

Researchers have sought to determine the interrelationship of the GP, TW2, and Fels methods of SA assessment. Vignolo et al. (1992) compared the three methods in a sample of male and female Italian adolescents. Their ages ranged from one to 17 years of age. Two independent investigators performed each method of assessment, and one observer reassessed all radiographs after six months again using all three methods. Both the TW-20 and TW-RUS methods were performed. Analysis indicated that all methods were adequate for assessing skeletal maturity in Italian adolescents. In a more recent study, van Lenth, Kemper, and van Mechelen (1998) used multiple investigators to compare the TW2 and Fels methods in a group of boys and girls with ages between 12 and 16 years. This sample was derived from the Amsterdam Growth and Health Study (AGHS) and produced four radiographs for each adolescent. The authors concluded that each method has acceptable intra-observer agreement, but no agreement exists between the SA ages derived from the two methods. The latter could be the result of different investigators performing each method. The differences between assessments reported Vignolo et al. (1992) were not as great which was likely due to the same observers conducting all three methods.

Comparison of the GP, TW, and Fels methods of SA assessment reveals good reproducibility within each method, but little agreement between methods. Consideration must be given to the reference population from which each method was derived when considering reference to future samples. The reference population should also be taken into consideration when using SA to predict adult stature. Predicting adult stature from SA is desirable in growth studies or clinically when a growth impediment is suspected and longitudinal data collection is impractical. All three, the GP, TW, and Fels methods of SA assessment have corresponding methods of adult stature prediction.

The development of the three main methods of SA prediction has also yielded methods of predicting adult stature. The GP method was the first and is the most commonly used method of SA assessment. It was also the first to have a corresponding method of adult stature prediction. Bayley (1946) was the first to publish a method to predict adult stature and it was based on tables derived from the GP standards. Bayley and Pinneau (1952) later revised this method to what is now commonly referred to as the Bayley-Pinneau (BP) method. This method is considered the most simple because it only requires current stature and current GP SA. Tanner et al. (1975) reported the first of a series of models developed to predict adult stature using the TW method of SA assessment. This method (TW) is a prediction model based on multiple linear regression equations. This method predicts adult stature based on three variables: present stature, chronological age, and TW skeletal age. The three variables are then multiplied by their corresponding correlation coefficients to predict adult stature. The latest version was reported in conjunction with the most recent TW3 method of SA assessment (Tanner et al., 2001). Similarly, Roche, Wainer, and Thissen [RWT] (1975) developed a multiple linear regression model, but used SA derived from GP method of assessment, recumbent length, and MPS. The RWT method was further improved by Khamis and Guo [RWT-KG] (1993), and requires the present stature of the child, body weight, mid-parent stature, and the Fels skeletal age. The greatest disadvantage of the RWT and RWT-KG methods is that they require the midparent stature of the biological parents. This is problematic because the midparent stature of the biologic parents for one or both is not always available. Missing parental statures can be replaced with national means, but this increases the individual error bound (Khamis and Roche, 1994). Since introduction of these three methods, researchers have sought to compare predictions made by these three methods to determine the relative accuracy of each.

The Fels method is the most versatile method of adult stature prediction, but requires many parameters in the calculation. Harris, Weinstein, Weinstein, and Poole

(1980) compared predicted adult statures using the BP, TW2HP, and RWT methods. Included in the study were the records of 22 male and 24 female adolescents from the Denver Child Research Council. Radiographs were taken from the ages of five years to 16 years. Also collected were the statures and weights of the children and the statures of the parents. The investigators were also able to follow up and collect the mature stature of each child. The investigators found that each of the prediction models underestimated mature stature. This underestimation is likely due to the fact that the investigators measured adult statures when the subjects were in their twenties, and the prediction models were based in subjects 18 years of age at the time of the last measurement. The results also demonstrated that the Fels method was the most accurate in predicting adult stature in both males and females. The investigators speculate that this is due to more information being used in the equation. Of the three methods, the TW2 was the least accurate. The investigators hypothesized that these differences were due to the different methodologies of SA assessment and the variables used in the prediction model. Since this study, revisions have been made to both SA assessment methods. Despite these improvements, the underlying differences in reference populations, methodology, and parameters exist. If simplicity is required and information is limited to the stature and SA of the child than the BP method is preferred. If the stature, weight, SA, and midparent stature of the child are available then the Fels method should be used. Nevertheless, one difficulty that these three methods have in common is the dependence on skeletal age.

Somatic maturity assessment. Assessment of secondary sexual characteristics and skeletal age are not always available or preferable due to their cost and the negative perception of undressing or exposing the children to radiation. Because of these negative perceptions, somatic maturity indicators have been studied as a method to estimate maturity. Somatic assessment involves measurements of the body dimensions and size. Body size itself is not an indicator of maturity and cannot be used directly to assess maturity (Malina, Bouchard, et al., 2004). Even with this limitation, somatic parameters can be used to identify the age-at-take-off, the age at peak height velocity, and percent of predicted adult stature. Both, peak height velocity and percent of predicted adult stature can be used as maturity indicators (Malina, Bouchard, et al., 2004).

All adolescents go through an adolescent growth spurt. The age-at-take-off refers to the age of the adolescent when they begin their growth spurt. The age-at-take-off in females occur at nine to 10 years of age and in males 10 to 11 years. The peak height velocity refers to the maximum rate of growth of the child. This occurs about the age of 12 in girls and 16 in boys. Girls tend to stop growing in stature about the age of 16 and boys about the age of 18. Both girls and boys can continue to grow beyond those ages. To ascertain peak height velocity or age-at-take-off, serial measurements must be collected over a wide range of years. This method befalls the same limitation as secondary sex characteristics because it is limited to a narrow time frame during the growth period and requires serial measurements. Percent of predicted adult stature however, offers an alternative for estimating somatic maturity and does not require serial measurements.

The percent of predicted adult stature is an expression of the child's current stature in relation to their predicted adult stature. A child who is closer to their adult stature is more mature than a child of the same CA and stature who is further from their adult stature. A child who is 80% of their adult stature is more mature than a child who is

75% of their adult stature when age and current stature are equal. Predicted adult stature can be derived from SA as described in the BP, TW3HP, and Fels methods. However, less invasive methods of predicting adult stature have been developed.

Assuming that SA would be impractical to acquire in most study designs, Wainer, Roche, and Bell (1978) developed a method of predicting adult stature without using SA. The investigators used the same data and regression model that was used to develop the RWT method. The investigators replaced SA with CA in the multiple regression models. The results yielded predictions that had only a small increase in error versus those obtained using SA. The major weakness of this method was the use of recumbent length because recumbent length is not always practical to measure. The KR method alleviates the need for recumbent length, and only requires current CA, weight, stature and midparent stature. The authors compared predictions using this new method to those using the RWT-KG method, and noted only small increases in imprecision. The 90% error bounds were 2.1cm for males and 1.7cm for females. Few studies have tested the validity of the KR method.

The validity of the percent of predicted adult stature has been compared to accepted methods of maturity estimation. Roche, Tyleshevski, and Rogers (1983) described the procedure for calculating the percent of predicted adult stature that a child has attained. To determine the usefulness of this measure as an indicator for maturity the authors correlated their predictions to known indicators of maturity. These included: peak height velocity, RWT skeletal age, GP skeletal age, and TW skeletal age. Predicted adult stature was calculated using both the RWT invasive method and the non-invasive method described by Wainer et al. (1978). Both methods of adult stature prediction yielded percents that were significantly correlated to all measures of maturity between the ages of 5 and 15 years in boys and 3 and 13 years in girls. This study demonstrates the applicability of percent of predicted adult stature as a maturity indicator in children and adolescents within the prescribed age ranges.

In summary, there are three common methods of assessing maturity. These include secondary sex characteristics, skeletal maturity, and somatic maturity. Secondary sexual characteristics typically include Tanner (1962) stages of genital, breast, testicular, and pubic hair development. In women, menarche can be used as another indicator. The limitation of secondary sex characteristics is the invasiveness and limited applicability to field studies. They are also limited by the narrow timeframe around the ages of puberty. Skeletal maturity is the best method to estimate biologic maturity because it encompasses growth from birth to full skeletal maturity. There are three commonly used methods to assess SA, but all require exposure to radiation and are expensive to conduct. Somatic maturity estimates involving age-at-take-off and peak height velocity require serial measures and are limited to a narrow timeframe similar to secondary sex characteristics. Calculating the percent of predicted adult stature shows great promise as an indicator for somatic maturity in adolescents. The KR method of predicting adult stature is noninvasive and it does not require SA. It can be readily applied in field studies, and has been shown to correlate well with the RWT-KG method. Further studies need to validate the application of the KR method in a variety of study designs and sample populations.

Injury Incidence, Risk, and Rates in Football

Injury Surveillance programs are generally conducted to describe and mitigate injury occurrence in a population. Injury surveillance can be applied to many different settings including automobile use, drug use, gangs, recreational sports, and more specifically football. The purpose of a surveillance program is to first describe the nature of the problem, identify interventions, and then monitor the affect the intervention has on the previously identified problem. Surveillance of injury in football is nearly as old as the game itself.

The history of injury surveillance in football. Concerns about injuries in football began shortly after the first game was played. The first recorded game of American football was played between Princeton and Rutgers universities in 1869. The 1905 season was terminated mid-season after what could be considered the first injury surveillance report was published in the Chicago Tribune (Cantu & Mueller, 2003). The article reported that 18 deaths and 159 serious injuries had occurred in the previous football season. That article prompted, not only rule and equipment changes, but it also highlighted the need for continued surveillance and further research describing the nature of injuries in football. The most serious and most studied injuries are those that include the head and spine.

Brain and spine related injuries have always been a major concern in football. Cantu and Mueller (2003a) recently examined brain injury-related deaths that have occurred in football in the years from 1945 to 1999. In a similar report, Cantu and Mueller (2003b) reported catastrophic spine injuries that occurred between 1977 and 2001. Both reports indicate a recent decrease in the frequency and rates of incidence in both types of injury. Catastrophic spinal injuries have decreased by 270% in last 10 years and deaths from football related brain injuries have decreased significantly since 1969. Both of these trends began following rule changes and educational campaigns. The importance of these two studies is that they highlight the need for continued injury surveillance, without which, these trends would not be detected and the effect of the rule changes and educational campaigns would remain unknown.

Many of the early and some current studies in football epidemiology were and are limited to cross-sectional and registry data derived from questionnaires, hospital records, and insurance claims. Those types of studies provide useful data regarding incidence of injury and the burden those injuries have on the healthcare system, but they provide little information about player specific injury data or risk factors. Registries also underestimate the true incidence of football injury because they will only include those injuries significant enough to warrant hospital visits, insurance claims, or were significant enough to be recalled from memory. More recently, with the availability of trained health care providers and the increased emphasis on injury definitions and exposure documentation, the quality of epidemiological data has significantly improved.

The defining of athlete exposures (AE) was an important step in the improvement of injury surveillance. Time of exposure has been identified as an important confounder that warrants consideration (Cahill and Griffith, 1978; Dagiau, Dillman, and Milner, 1980). Powell (1980) defined AE as any opportunity for an athlete to become injured in a coach directed session. Each player present at each practice or competition was counted as one exposure. Powell's research was conducted as part of the National Athletic Injury/Illness Reporting System (NAIRS) during the 1975 to 1978 seasons. The NAIRS study can be considered the beginning of modern sports epidemiology. The definitions of injury and AE used in NAIRS continue to be used. The study reported by Garrick and Requa (1978) and the NAIRS study were the first to use trained healthcare providers in the form of Certified Athletic Trainers (ATC) to document injuries and exposure information. The ATC reported injury data were a significant improvement in quality and quantity of information. The NAIRS study was also one of the first to calculate injury rates that were based on the total AE.

The risk of injury increases with age. It is unknown if this is a function of intrinsic factors related to aging or if it is related to the increased level of competition as competitors progress through the ranks. Because of this relationship, college, high school, and youth football players should be considered separately. Maturity should be considered in any study that includes youth football players younger and older than the average age of puberty (10-12 years-of- age for males). For this reason, this review focused on college, high school, and youth football injury incidence separately with emphasis placed on junior high school and youth players due to their proximity to the age of puberty.

College football injury incidence, risk, and rates. Injury incidence, risk, and rates have been thoroughly reported at the college level of competition. This is due to the availability of data collectors and the cooperative nature of university medical professionals in the production of research. Examining college football players as part of the NAIRS study, Powell (1980) reported injury rates per 1000 AE. Injuries were defined as any incident that required cessation of activities the following day or subsequent days following the event, concussions, dental injuries, or any injury requiring substantive medical attention. The injury rates were 7.0 and 63.0 per 1000 AE for practices and games respectively. These rates were based on over 1.4 million AE, seven percent of which were attributed to game exposures. Sixty percent of the injuries reported occurred to the lower extremity and 20% occurred to the upper extremity. The knee was the most commonly injured body region (20.5%). More recently, Powell and Dompier (2004) reported injury risk and rates that were similar, but also included a definition of injury that included a non-time loss component. Powell and Dompier found that the previous NAIRS definition accounted for about 25% of the total injury picture in football. College level data provides a good reference point, but because the vast majority of college age athletes have stopped linear growth, further review was limited to high school, junior high school, and youth football studies.

High school football injury incidence, risk, and rates. The injury risk and rates of high school football players have been extensively described, but maturity is rarely considered. Maturity should be considered in this demographic because most males begin puberty between the ages of 10-12 and complete their adolescent growth spurt at the age of 16 on average (Malina, Bouchard, et al., 2004). Few studies involving high school age football players consider maturity as a possible confounder. Maturity has been difficult to assess accurately and logistically, and has therefore, not been included in many studies involving football injury. Because maturity is rarely considered, injury risk for those who are less mature may not be adequately represented. Players who are larger, stronger, and more mature receive the majority of playing time in football.

The majority of available research regarding high school football is descriptive in nature. Prior to the NAIRS study, Bylth and Mueller (1974) sought to describe injury in high school football players in North Carolina. Injury was defined as any event occurring during football that restricts participation one day following the day that the injury occurs. Player demographics were collected by interview at the beginning of the seasons and injuries were reported to the investigators on a weekly basis by the coaches. The risk (number of injuries divided by number of players) was 48%. Players who were older, heavier, taller, and had more experience had higher risk of injury. The greatest limiting factor to this early study was the reporting of injuries by coaches and lack of exposure information.

The study of injury in youth and high school football was greatly improved with the inclusion of ATCs as data collectors. Garrick and Requa (1978) conducted one of the early studies utilizing ATCs as the primary injury data collectors. Injury was defined as any event that required removal from practice or caused the absence of subsequent sessions. There were 506 injuries reported for an injury rate of 81 injuries per 100 players. That injury rate was nearly twice the rate reported by Blyth and Mueller (1974) and is likely due to the increased sensitivity of the injury definition and trained data recorders. Other studies have further described injury incidence in high school football players and have reported similar results (Beachy, Akau, Martinson and Olderr, 1997; Culpepper and Niemann, 1983; Delee and Farney, 1992; Powell and Barber-Foss; 1999).

The inclusion of AE further improved the analysis of injury data. The bulk of research involving high school football players is limited to small demographic areas and cannot be widely generalized. Powell and Barber-Foss (1999) conducted one of the largest and most comprehensive studies involving high school football players. There were 246 high schools included in the study, and athletic trainers collected data. The sample included a normal distribution of schools with small to large enrollments. The injury definition included that previously described by Powell (1980). Exposures were classified as team-seasons, player-seasons, and AE. There were 400 team-seasons, 6831 player-seasons, and 1.3 million athlete exposures reported. There were 10557 reported football injuries amongst 7310 injured players. The player rate of injury was 34.6, the case rate was 50.0, and the injury rate per 1000 AE was 8.1. Practices accounted for 56.4 percent of the injuries. The case rate per 1000 AE for practices was 5.3, but for games it was 26.4. This indicates that players were injured fives times more often in games than in practices. Powell and Barber-Foss further described injury as minor, moderate and major. These were based on the number of days lost from participation due to injury. Minor injuries were those that lost less than eight days, moderate were between eight and 21 days, and severe were greater than 21 days. Minor injuries accounted for 73% of the injuries while moderate and major accounted for 16% and 11% of the injuries respectively. These data provide a good overview of injury to high school football players but to more accurately understand the influence of maturity on injury, examination of injury in youth football players is needed.

Youth football injury incidence, risk, and rates. Incidence of injury increases with each succeeding level of football from youth to college. For the purposes of this dissertation, youth football players were considered those in primary and junior high school, or those below the ages of 16 years. It is unknown if the age affect is confounded or mediated by maturity. The injury incidence, risk, and rates of high school, junior high school, and youth footballers are summarized in Table 1.

The differences between high school and younger players are apparent. The first study to focus on junior high players found a risk of 37% (Violette, 1976) as compared to the nearly 49% (Bylth and Mueller, 1974) reported for high school players using the same study model and cohort. Other studies have reported high school injury risks that range between 18.4% (Turbeville et al., 2003b) and 81% (Garrick and Requa, 1978). Comparatively, Stuart et al. (2002) reported risk as low as 3% in fourth graders, but Radelet et al. (2002) reported injury risk in youth as high as 51%. Injury rates follow a similar pattern with the lowest reported by Radelet et al. (0.43 per 1000 AE) for the youngest age groups while Turbeville et al. (2003a) reported the highest for middle school players (9.9 per 1000 AE). Comparatively, Powell and Barber-Foss (1999) reported an average injury rate of 8.1 per 1000 AE for high school players and Powell and Dompier (2004) reported an injury rate of 40 per 1000 AE for college players. This age effect is further demonstrated within subgroups at the youth level.

An increasing risk of injury is seen in youth football players within succeeding groups. Stuart et al. (2002) reported that 3% of the fourth graders were injured while 11% of the eighth graders were injured. Malina et al. (2002) found similar proportions with the fourth grades having the lowest and the eight graders having the highest rates. Turbeville et al. (2003a) found a 10% incidence in middle school players, and 18% in high school players (Turbeville et al., 2003b). Combined injury rates have ranged from 0.43 (games only) (Radelet et al., 2002) to 8.84 (Turbeville et al., 2003a), with the highest at 10.4 (Malina et al., 2002) per 1000 AE. Turbeville et al. (2003a, b) directly compared participants from middle school and from high school. Injury rates per 1000 AE for high school players were 1.31 for practices, 13.12 for games, and 3.20 overall. In middle school players, the injury rates per 1000 AE were 0.97 for practices and 8.84 for games. It is unknown if this age affect is confounded or mediated by maturity or other factors.

Descriptive epidemiological studies have described injury risk in high school and youth football. From these data, testable hypotheses regarding risk factors for injury can be derived. Few studies have investigated risk factors for injury in football and even less have examined risk factors in youth players. The identification of risk factors is important for two main reasons. First, identification of injurious conditions, rules, or equipment aids decision makers in the development of policies, rules, and equipment changes. As in all analytic epidemiology, special care must be taken to identify and control possible confounders. In youth football, one such confounder rarely considered is maturity status.

Risk Factors for Injury in Football

Few studies have thoroughly examined both extrinsic and intrinsic variables and their relationship to injury. Extrinsic variables are those that are not directly affecting the subject, and changing the variable in some way does not require modification of the athlete. Intrinsic or player related variables are those that are directly related to the player. These would include exposure time, stature, weight, fitness level, age, psychological profile, and maturity to name a few. Most player-related variables cannot be changed, but some can be modified. Age, maturity status, or stature for example, cannot be changed, but factors such as their weight and fitness level can be changed. Intrinsic variables require player level analysis that is labor intensive and requires diligent assessment and frequent follow up. Only recently, have there been studies that have considered these variables in football, but even less have considered them in youth football.

Table 1

Summary of Injury Incidence, Risk, and Rates in High School, Junior High, and Youth Football Players

Investigator	Setting	Data Source	Players	Injuries	*Incidence	§ Injury Rate
Beachy et al. (1997)	HS & JHS	ATC	1278	2503	£197%	NR
Blyth et al. (1974)	HS	Coach	8776	4287	48%	NR
Delee & Farney (1992)	HS	ATC	4399	2228	51%	3 per 1000 hrs exp
Garrick & Requa (1978)	HS	ATC	624	506	81%	NR
Linder et al. (1995)	JHS	Coach	340	55	16%	NR
Powell & Barber-Foss (1999)	HS	ATC	21122	10557	50%	8.1 per 1000 AE
Radelet et al. (2002)	Youth	Coach	252	129	51%	15.0 per 1000 AE
Stuart et al. (2002)	Youth	Physician	915	55	6%	8.5 per 1000 AG
Tuberville et al. (2003a)	JH	ATC	646	64	9.9%	2.0 per 1000AE
Turbeville et al. (2003b)	HS	ATC	717	132	18.4%	3.20 per 1000 AE
Violette (1976)	JH	Interview	108	40	37%	NR

AE = Athlete exposures for both practices and games
AG = Athlete game exposures
NR = Not Reportable
£ Occurred over 7 years
* Number of injuries divided by the total number of players
§ Number Injuries divided by exposure

Exposure time. An early study by Dagiau et al. (1980) demonstrated the importance of exposure time to injury rates in football. More specifically, the authors wanted to test if there was an optimal time that a player should be exposed to a specific practice or game condition. The investigators followed the University of Illinois varsity football team for two seasons. Injury risk decreased with an increased number of plays. For practices however, there was an increased risk of injury with increased time of exposure. Cahill and Griffith (1979) conducted a more comprehensive study of exposure, injury, and other variables in football. This study was important because it identified exposure time as a risk factor for injury in football, but as the authors indicate, there is likely a systematic bias that affected player exposure time. If a player does not sustain an injury, he will continue to participate in more plays during the game where an injured player will have systematically less because he was removed.

Exposures can be measured at three progressive levels of specificity. The most general form, or sport level, would be to simply multiply the number of players on the team roster by the number of games and practices. This provides a crude exposure figure, but over estimates the denominator that in turn leads to an underestimation of injury rate. The underestimation occurs because players who do not participate in a practice or play in a game for any reason are still counted as an exposure. The second level of exposure calculation is at the team level. This method tallies daily exposure as number of participants present at each session or the number that participate in each game. If a player is not present for any type of session or do not play in a game, they are not counted. This is more sensitive than the first and is likely to produce higher rates because the denominator will be smaller. The third level of exposure analysis is at the individual player level. These exposures are expressed as either player hours of exposure or the number of repetitions of exposure. Measuring the player level of exposure is time intensive and difficult to achieve, but will control the exposure bias described by Cahill and Griffith (1979).

Playing surface and shoe interface. The shoe surface interface was one of the first extrinsic variables to be examined and demonstrated to be a risk factor in football. One of the first studies to report this relationship was that of Torg and Quedenfeld (1971). Their hypothesis was that the traditional seven by 3-quarter inch cleat shoe was responsible for a disproportionate amount of knee injuries. During the first year of the study, all athletes wore the traditional shoe, but in subsequent years, one league wore a soccer style shoe and another league wore a short molded 14-cleat shoe. The number of knee injuries significantly decreased in both leagues during the two intervention seasons. Similarly, Blyth, Mueller and Frederic (1974) reported significant reduction (30.5%) of knee and ankle injuries when playing surfaces and a 48% reduction when provided with both the resurfaced field and soccer shoes.

Artificial turf has been implicated as a risk factor for injury in football because of higher levels of friction between the shoe and surface when on it. Bramwell, Requa, and Garrick (1972) conducted a study to determine if grass or artificial playing surfaces were risk factors for injury during football games. Also included in the analysis were the surface conditions (wet or dry) during each event. Bramwell et al. (1972) found that injury rates were higher on artificial turf, but injury rates were lower on both artificial and natural surfaces when they were wet. Powell and Schootman (1993) provided further support that artificial surfaces are related to injury. Ankle injury rates on artificial surfaces were significantly higher than on natural grass. Multivariate analysis revealed that this difference was only present in specific combinations of player position, play type, and type of surface. Orchard and Powell (2003) found similar finding, but noted that lower ambient temperatures also contributed to lower injury rates. The investigators hypothesize that this is due to the reduced shoe-surface friction.

The associations noted in the studies above may have been affected by league rule changes. An important point regarding the timeframe of some of these studies was that in 1974 National Football League [NFL] (2004) began making drastic rule changes in an attempt to reduce the severity and incidence of lower extremity injuries. These included moving the goal posts to the back of the end zone, eliminating roll-blocking, cut blocking of wide receivers, and wide receivers were no longer allowed to block below the waist (NFL, 2004). The infamous crackback block was not outlawed in the NFL until 1979, but it is unclear to what extent these concerns or rule changes were in focus at any level of football prior to the NFL rule changes.

The data support that injury risk is associated with the shoe and playing surface interface. This has been accepted to such an extent that specialized shoes and even new types of artificial turf have been developed to mimic natural playing surface characteristics. However, the many risk factors were not controlled in the early studies and only the studies by Powell and Schootman (1993) and Orchard and Powell (2003) attempted to systematically control for other factors that may have confounded earlier studies.

Fitness level. Fitness level is one of the most studied intrinsic variables associated with football. Cahill and Griffith (1978) reported the effects of an intervention consisting of a six-week preseason-conditioning program on knee injuries. The authors found a significant reduction in knee injuries during the intervention period. The greatest injury reduction occurred among the linemen (61%) followed by the backs (20%). Gomez et al. (1998) examined the relationship of body fatness and lower extremity injury rates in junior high and high school linemen. Gomez et al. found that lower extremity injury risk increased as BMI increased. The most comprehensive and well-controlled study of player fitness to date was that of Turbeville et al. (2003a, b). Player variables measured included: experience, position, injury history, BMI, weight, stature, and grip strength. Logistic regression was used to determine odds ratios associated with each parameter. Injured players were on average older, had a higher BMI, were stronger, had more experience, had a history of previous injury, and used optional equipment. When only those considered were first-string players (controlled exposure), the only parameters that remained significant were BMI, grip strength, years of experience, and injury history. When exposure was uncontrolled, injury history and experience demonstrated the greatest risk of injury. When exposure was controlled, the lineman position and experience remained significant.

Psychological variables. Thompson and Morris (1994) took a different approach and examined the relationship of injury with psychological variables. Analyses of the relationship of stressful life events, anger, and attention were examined in 120 high school football players. Players were followed for the duration of the 1987 football season. The psychological instruments were administered at the beginning of the season. Logistic regression revealed that players with high levels of anger directed outward, those with elevated recent stress, and those with low focused attention were at the greatest risk of injury. The authors of this study propose that children who are distracted by stressful events in their life or are angry are less focused on playing the game and are therefore at greater risk.

Player position and game situations. Specific player positions are at greater risk for injury than others. Blyth et al. (1974) demonstrated that the halfback position was the most commonly injured in high school football players. Powell and Schootman (1993) supported the findings of Blyth et al. by comparing NFL ankle injury rates with the type of surface, player position, and type of play ran by the offense. Multivariate analysis revealed that injury was related to specific combinations of player position, play type, and type of surface. Powell and Schootman also found that player position also dictates which injuries specific player positions are most susceptible. As indicated by these studies, player position and type of play contribute to the variability of the injury model.

Maturity status. Few studies have considered maturity as a risk factor or confounding variable in the study of youth football injury, and those that have are inconsistent. As part of the North Carolina Football Study, Violette (1976) was one of the first to attempt to answer this question by examining football injuries in junior high school players. Using the same design as the original study, Violette used secondary sexual characteristics to group junior high school football players by maturity status. Violette found that those who were less mature were at significantly greater risk of injury than their more mature teammates. Comparatively, Linder et al. (1995) found that those who were most sexually mature were more likely to be injured. The most recent study by Malina et al. (2002) found no relation between maturity status and injury when PPAS was used to group players by maturity status. Many differences exist between all three studies contributing to the lack of consistency.

The three studies that examined maturity as a risk factor for injury in youth football players had different definitions of exposure, but used similar definitions of injury. Linder et al. (1995) did not consider exposure, but Violette (1976) used a sport level of exposure and Malina et al. (2002) used a team level of exposure. Injury definitions were similar and included any football related injury that required removal from the current or subsequent sessions. The method by which injuries were documented was the most significant difference between the three studies. Violette used coaches to report injuries to an investigator who would then complete an interview. Linder et al. asked coaches to report injuries, and Malina et al. had ATCs onsite collecting, evaluating, and documenting injuries. It is difficult to determine if the method used by Violette or Linder et al. was more sensitive, but the inclusion of ATCs onsite would definitively make the method of data collection used by Malina et al. the most sensitive. Increased sensitively would cause a greater number of injuries to be documented. Analysis of data also varied, and the analyses by Malina et al. were the only to include multivariate logistic regression.

Multivariate analysis of injury and the suspected associated variables is needed to rule out confounding variables. Malina et al. (2002) used logistic regression to examine injury and maturity in context of other suspected risk factors. Risk factors included previous injury, stature, weight, chronological age, previous sport experience, previous football experience, and psychological variables. The only significant factors related to injury reported by Malina et al. were stature and previous injury.

Injury in football is multifactorial. Both extrinsic and intrinsic factors contribute to the injury model. Extrinsic factors include the sport played, level of play, weather, player position, playing surface, surface condition, equipment, and rules. Intrinsic factors include age, sex, stature, weight, BMI, fitness, psychological status, and injury history. Modifiable extrinsic factors include rules, exposure time, surface condition or type, and equipment. Modifiable intrinsic factors include fitness level, weight, BMI, and some psychological parameters. In children, maturity status, even though it is not modifiable, should be considered a confounder. No studies to date have examined all potential risk factors simultaneously. To do so would be difficult, and not all risk factors are relevant to every research question or situation.

Summary of the Literature

The main purpose of this review was to examine whether maturity status should have any bearing on sport classification in youth football. To answer that question, two areas of research were reviewed. First, applicable measures of maturity status were compared and contrasted. These included sexual maturity status, skeletal maturity status, and somatic maturity status. Assessment of each form of maturity status has strengths and weaknesses based on the study characteristics and limitations. Skeletal age is the single best estimate of maturity status, but is costly and exposes children to radiation. Secondary sexual characteristics are the most widely used method of estimating maturity status, but this method potentially limits participant willingness to be included because of the embarrassing nature of the examination. Somatic maturity estimation using the percent of predicted adult stature, although relatively untested in youth football players, shows the most promise for field studies where invasive methods are not applicable or desirable.

The second stage of this review examined injury incidence and risk factors for injury in football with special emphasis on studies involving high school age players, or when available, youth players. Injury mechanisms in football are multifactorial and involve the interaction of numerous risk factors. Risk factors include both controllable and uncontrollable extrinsic and intrinsic variables. Maturity status is an uncontrollable risk factor that is of particular interest to the current study. This factor has also been the least studied in the youth football population. Maturity status must be determined or refuted to be a risk factor for injury before recommendations can be made regarding sport classification using maturity status as a factor.

Chapter Three

Methods

A child's level of maturity may be a risk factor for injury. If so, competition levels should be arranged according to maturity status versus age or grade level. Few studies have systematically studied risk factors for injury in football and even fewer have considered maturity in the injury model. The purpose of this study was to determine the validity of the Khamis and Roche [KR](1994) method for predicting adult stature (used to determine maturity status) in youth football players, and to analyze maturity status in univariate and multivariate models of injury risk.

Overview

The current study was a 2-year subset from a 4-year observational cohort of youth football players that began at the start of the 2000 football season and continued through 2003. The data used in the current study were obtained during the 2002 and 2003 seasons. The original intent of the study was to examine suspected risk factors for injury in youth football players. Independent variables such as maturity, anthropometric measures, injury history, participation history, psychological variables, player position, and surface conditions were included. The overall study has used percent of predicted adult statures derived from adult stature predictions using the KR method.

Research Design

The study consisted of two separate designs. The first consisted of a cross-sectional design, and the second consisted of an observational cohort design. The convenience sample used in the first leg of the study was a subset of the larger cohort observed as part of the second leg of the study. The specific research questions and null hypotheses were:

1. Is the Khamis and Roche (1994) method a valid estimator of predicted adult stature?

   $H_0 1$: No linear relationship exists between the predicted adult statures derived from the Khamis and Roche (1994) and Khamis and Guo (1993) methods.
2. Is Khamis and Roche (1994) method of predicted adult stature a valid measure of maturity when expressed as a percentage of the predicted adult stature?

   $H_0 2$: No linear relationship exists between percent of predicted adult stature derived with the Khamis and Roche (1994) method of adult stature prediction and skeletal age.
3. Is maturity a risk factor for injury in youth football players?

   $H_0 3$: No relationship exists between maturity status and injury.

Subjects

The subjects consisted of youth football players in grades 4^{th}-8^{th} from two communities that participated in the Mid-Michigan Pony Football League in south-central Michigan during the 2002 and 2003 seasons. By league rules, 4^{th} and 5^{th} graders were grouped together on the same teams and were therefore considered as one group (4-5^{th}) during data collection and analysis. The subjects in this study were a convenience sample. The criteria for inclusion were registration in the youth football league and informed consent from both the parents and participants (Appendices A, B).

An additional convenience sample of 64 children volunteered to participate in the validity component of the study. An equal distribution across grade levels was sought. Additional criteria for inclusion in this component included no history of fracture to the left upper extremity, the completion of an additional informed consent (Appendices C, D), and no medical conditions that would preclude radiographic examination.

Instrumentation

Player demographic information and previous sport experience, previous injury, and parental statures were obtained from surveys distributed with the parental informed consents (Appendix E). Player stature was measured to the nearest 0.1 cm using a field anthropometer (GPM Anthropological Instruments). Weight was measured to the nearest 0.2 kg using a digital scale (Taylor Precision Products LP). Stature and weight measures were taken following the procedures outlined by Malina et al (2002). Previously reported standard error of measure using the same procedure was 0.22 cm (Malina et al. 2002). The standard error is within the range of measurement variability in surveys of children (Malina and Bielicki, 1996). The participants in the validation study also had their statures and weights taken at the time that the radiograph was taken as required by procedures outlined by Roche et al. (1988).

Certified athletic trainers served as data collectors and documented injuries and exposures. A standardized reporting form (Appendix F) was used to maintain consistency between the two communities. Daily exposures were tallied by counting the number of participants present at each session and confirmed with the count reported by each coach. Data recorders listed exposures by town, grade, and type of session (game or practice). A licensed and experienced radiological technician took the radiographs during scheduled dates and at the convenience of the participants. The Fels SA with standard error of measure (SE) was determined using the Fels software (FELShw version 1.0).

Procedures

This study had two distinct stages. The first stage consisted of the validation of the PPAS as an estimate of maturity in a group of youth football players. The second stage consisted of the injury risk analysis. Informed consent was obtained prior to all data collection from the parents and children using procedures outline by the University Committee on Research Involving Human Subjects (UCRIHS).

Stage one, validation of percent of predicted adult stature. Volunteers for participation in the validation study were sought at the time of equipment handout. Those who volunteered for the validation study were asked to provide contact information and were informed that they would be contacted at a later time. Originally, random selection of volunteers for each age group was planned, but due to an insufficient number of volunteers, the final group of volunteers was a convenience sample. Some volunteers who were contacted chose to not participate which resulted in all volunteers being contacted negating any random selection. There were 78 parents and children who volunteered, of those, 64 agreed to participate and completed the x-ray. Investigators were present at the radiology center at all scheduled times and obtained informed consent, the parents' reported statures, each child's current stature, current weight, and DOB.

The specific guidelines for radiographic analysis outlined by Roche et al. (1988) were followed. The specific guidelines included a posteroanterior view of the left hand that includes 3 cm of the distal radius and ulna. The forearm, palm, and fingers were in contact with the cassette. The fingers were fully extended with the 3rd inline with the forearm, and the distance of the central tube-to-film was 91.4 cm (36 inches). Lastly, the central ray was directed at a right angle to the distal end of metacarpal three.

An expert with years of experience estimating SA using the Fels method examined the radiographs. The Fels method uses a set of criteria as maturity indicators that are based primarily on a variety of shape changes and ratios derived from several linear measurements of long bones (Roche et al., 1988). Measurements are made to 0.5 cm. Grades are then assigned to each indicator, and are then entered into the FELShw 1.0 computer program (Roche et al., 1988). The software program then produces a SA with SE. The SA can then be used to predict adult stature following the RWT-KG method.

Prediction of adult stature using SA was performed using the RWT-KG method (Khamis and Guo, 1993). The parameters included in the RWT-KG method are the child's current stature, weight, SA, and the MPS of the biological parents. These variables were entered into a regression equation and factored with age specific coefficients described by Khamis and Guo. Tables provided by Khamis and Guo list coefficients for all chronological ages from three to 17.5 years. The corresponding CA in the table indicates which coefficients to use in the equation. The equation is as follows, where β is the coefficient:

$$\text{RWT-KG PAS} = \beta o + (\beta_{Stature} * \text{stature}) - (\beta_{weight} * \text{weight}) + (\beta_{MPS} * \text{MPS}) - (\beta_{SA} * \text{SA})$$

Prediction of adult stature using the KR non-invasive method is similar (Khamis and Roche, 1994) to the RWT-KG method. The variables used in this method include current CA, current stature, current weight, and MPS. The non-invasive KR method has been shown to have only a slight increase in the 90% error bounds when compared to the invasive RWT-KG method. The 90% error bounds for males are 1.8 inches and 2.1 inches for the RWT-KG and KR methods respectively (Khamis and Roche, 1994). For females, the 90% error bounds are tighter (RWT-KG = 1.5 inches; KR = 1.7 inches). The equation for the KR method, where β is the coefficient, follows:

$$\text{KR PAS} = \beta o + (\beta_{\text{Stature}} * \text{stature}) + (\beta_{\text{weight}} * \text{weight}) + (\beta_{\text{MPS}} * \text{MPS})$$

It was impractical to obtain measurements from all parents in the current study so reported parental statures were obtained. The parent self-reported statures were corrected for over-estimation. Wing, Epstein, and Neff (1980) have shown that adults over-estimate stature by an average 1.7 inches. Himes and Roche (1982) and Himes and Faricy (2001) have shown reported statures to be useful proxies when measured parental statures are not available. The correction used in the current study is the same method reported by Epstein, Valoski, Kalarchian, and McCurley (1995) and later used by Roemmich et al. (1996).

$$\text{Corrected MPS}_{\text{males}} = 2.316 + (0.955 * \text{stature/inch})$$

$$\text{Corrected MPS}_{\text{females}} = 2.803 + (0.953 * \text{stature/inch})$$

The predicted adult stature is used to calculate the PPAS. The children's PPAS were calculated by dividing the children's current stature by their PAS. Statistical analyses of the stage one data included calculation of partial correlations between the SA and PPAS for both the total sample and within each grade level while controlling for CA. Additionally, a two-tailed t-test was used to compare the means of PAS using both the RWT-KG and KR methods. The Statistical Package for Social Sciences (SPSS 10.0) was used to perform all statistical procedures. This KR method of determining PPAS was also used to estimate maturity in the injury analysis stage of the study.

Stage two, injury analysis. The second stage of this study involved the continuation of the original injury surveillance model that began in August 2000. An ATC was present at every practice and every home game to document injuries (Appendix F), athlete exposures, and to provide first aid and basic athletic training services when appropriate. Detailed information regarding specific injury variables was collected for each injury (Appendix F). The coaches of teams that had away games were queried at the first practice of the following week regarding injuries and exposures that occurred during the away game. All reported injuries were followed up with the player and or parents for accuracy and completeness. Athlete exposures were counted on a daily basis by the ATC and each player present at each session was counted as one exposure (team level).

Injury was defined as any incident that required ATC evaluation and assessment, or those that were reported by coaches during away games. Injury was further classified as time-loss (TL) or non-time-loss (NTL) based on whether or not the athlete was returned to sport. If the athlete was evaluated and returned to participation the same day, the injury was classified as NTL. If the athlete was removed from participation that day, missed subsequent sessions, or sought medical attention then the injury was classified as TL. This definition is more sensitive than that reported by Powell and Dompier (2004), but was necessary to accommodate the sporadic practice schedules of many of the teams where daily follow-up was impossible.

Injury analysis included descriptive and analytic procedures. Using the injury and exposure incidence data, injury risk and injury rates were calculated for each age group. Univariate analyses for specific intrinsic variables was performed with the data as a whole and stratified by grade. Backwards-stepwise logistic regression was used to control for all significant variables simultaneously. Odds ratios and 95% confidence intervals (CI) were reported for the final model (Motulsky, 1995). The Statistical Package for Social Sciences (SPSS 10.0) was used to perform all statistical procedures.

Chapter Four

Results

The purpose of this study was to determine the validity of the Khamis and Roche [KR](1994) method for predicting adult stature as an estimator of maturity in youth football players, and to analyze maturity as a risk factor for injury using epidemiologic methods of analysis. Two distinct stages of data collection and analysis were performed.

Stage One: The Validity of Percent of Predicted Adult Stature

Stage one was conducted to determine the validity of percent of predicted adult stature (PPAS) as an estimate of maturity. Stage one data collection consisted of collecting x-rays, current stature, current weight, date of birth, and the midparent stature (MPS) from a convenience sample of youth football players during the 2003 season. The stage one data were used to calculate adult statures using the KR and Khamis and Guo [RWT-KG](1994) methods. Current statures were then divided by adult stature estimates to produce the percent of predicted adult stature (PAS). Inferential statistics included partial correlations correcting for chronological age (CA), and two-tailed t-tests. The specific stage one research questions and null hypotheses included:

Q1: Is the KR method a valid estimator of predicted adult stature?

$H_0 1$: No linear relationship exists between the predicted adult statures derived from the KR and RWT methods.

Q2: Is KR method of predicted adult stature a valid measure of maturity when expressed as a percentage of the predicted adult stature?

H_02: No linear relationship exists between the percent of predicted adult stature derived with the KR method of adult stature prediction and skeletal age.

Participant demographic data. A total of 64 (85% of the target) youth football players participated in stage one of this study. The means for chronological age, skeletal age, stature, and weight are presented in Table 2. This sample represents 16% of the 2003 season population from each age group with the exception of the 4-5th graders (13%). The sample proportions were 31%, 28%, 25%, and 16% for 4-5th, 6th, 7th, and 8th grades respectively. For the purpose of comparison, the mean difference between CA and SA was calculated by subtracting each subject's CA from their SA. The mean difference between SA and CA was 0.7 years with the 8th grade having the highest mean difference (1.4) while the 4-5th graders had the smallest difference (0.2). The skeletal ages were higher than the chronological ages for all grades indicating that the sample is on average advanced in skeletal maturity. The percent of adult stature calculated using SA (RWT-KG) is higher than the KR percent adult statures for all grades except 4-5th as shown in Table 3.

Table 2

Grade Specific Mean Ages and Physical Characteristics for 64 Youth Football Players

		CA (yrs)		SA (yrs)		Stature (cm)		Weight (kg)	
Variable	n	M	SD	M	SD	M	SD	M	SD
4-5th	20	10.50	0.72	10.74	1.55	144.35	7.94	45.56	12.83
6th	18	12.03	0.45	13.08	1.24	156.17	8.46	54.96	14.49
7th	16	12.81	0.78	13.44	1.51	157.39	8.31	60.55	24.63
8th	10	13.93	0.16	15.36	1.28	169.75	8.13	69.52	15.78
All Grades	64	12.05	1.36	12.80	2.10	154.90	11.69	55.69	18.85

Partial correlations and t-tests. Statistical analysis consisted of partial correlations and two-tailed t-tests. Partial correlations were used to control the covariance associated with CA. Percents of predicted adult statures were moderately, but significantly related to SA (partial r, adjusted for CA, = 0.54; $p < .001$). Grade specific partial correlations for percents of predicted adult statures and SA are presented in Table 4. The grade specific partial correlations that were significant were limited to the 7th graders (partial r, adjusted for CA, = 0.78; $p < .001$), and the 5th graders (partial r, adjusted for CA, = 0.57; $p < .05$).

Table 3

Mean Predicted Adult Statures and Percents of Adult Statures for 64 Youth Football Players by Grade

		Predicted Adult Stature				Percent of Adult Stature			
		KR		RWT-KG		KR		RWT-KG	
Variable	N	M(cm)	SD	M(cm)	SD	M %	SD	M %	SD
4-5th	20	178.18	5.90	178.77	5.71	80.99	3.05	80.73	3.24
6th	18	183.35	7.18	181.34	6.12	85.17	2.82	86.09	2.75
7th	16	177.97	6.35	177.56	5.19	88.45	3.83	88.66	4.37
8th	10	181.29	7.00	178.83	5.88	93.63	2.53	94.91	2.95
All Grades	64	180.07	6.83	179.20	5.77	86.01	5.33	86.44	5.83

The RWT-KG and KR methods of adult stature prediction were strongly related (partial r, adjusted for CA, = 0.88; $p < .001$) Table 4. Partial correlation also revealed that percents derived from the KR and RWT methods were strongly related (partial r, adjusted for CA, = 0.85; p < .001).

Table 4

Partial Correlations Controlled for Chronological Age by Grade

Group	N	Maturity SA / KR	Predicted Stature KR / RWT-KG	Percent Stature KR / RWT-KG
4-5th	20	0.57*	0.90†	0.85†
6th	18	0.47	0.87†	0.83†
7th	16	0.78†	0.96†	0.90†
8th	10	0.66	0.94†	0.86†
All Grades	64	0.54†	0.88†	0.85†

* $p < .05$ ** $p < .01$ † $p < .001$

A two-tailed t-test was used to compare the sample means derived from the KR and RWT-KG methods of adult stature prediction. There was a significant effect for PAS, $t(63) = 2.29, p < .05$. Two-tailed t-test results are reported for adult statures by grade in Table 5. All group differences for adult statures were significantly different except for the 4-5th (PAS, $t(19) = -1.27, p > .05$) and 7th grades (PAS, $t(15) = 0.59, p > .05$). Similar results were found when the sample means of the percents of adult statures were compared using a two-tailed t-test (Table 6). There was a significant effect for PPAS, $t(63) = -2.35, p < .05$.

Table 5

Paired T-Test Results for Stature Prediction Methods by Grade

Group	df	M difference	SD	95% CI Lower	95% CI Upper	t	p
4-5th	19	-0.59	2.09	-1.57	0.39	-1.27	> .05
6th	17	2.00	3.36	0.34	3.68	2.54	< .05
7th	15	0.41	2.79	-1.08	1.90	0.59	> .05
8th	9	2.45	3.19	0.17	4.74	2.43	< .05
All Grades	63	0.86	3.03	0.11	1.62	2.29	< .05

Table 6

Paired T-Test Results for Percent of Predicted Adult Stature Methods by Grade

Group	df	M difference	SD	95% CI Lower	95% CI Upper	t	p
4-5th	19	0.27	0.98	-0.19	0.72	1.22	> .05
6th	17	-0.92	1.55	-1.70	-0.15	-2.52	< .05
7th	15	-0.21	1.37	-0.94	0.52	-0.62	> .05
8th	9	-1.28	1.68	-2.48	-0.08	-2.41	< .05
All Grades	63	-0.43	1.46	-0.79	-0.06	-2.35	< .05

Stage Two Results: Injury Analysis

Stage two of the study consisted of injury analysis and sought to describe and examine intrinsic player risk factors. Analysis of risk factors included both univariate comparisons of relative risk and odds ratios derived from backwards-stepwise logistic regression. The specific research question and null hypothesis addressed was:

Q3: Is maturity a risk factor for injury in youth football players?

H_03: No relationship exists between maturity status and injury.

Descriptive epidemiology. During the 2-year study period, there were a total of 779 youth football players in grades 4 through 8 who participated in stage two of the study. Fourth and 5th graders were combined on the same teams as per league rules and we therefore included them in the analysis as one group. The 4-5th grade teams had the highest participation (296) while the 8th grade represented the lowest (92). Player demographic data are presented in Table 7 by grade. The mean ages were 10.1, 11.4, 12.5, and 13.4 for grades 4-5th, 6th, 7th, and 8th respectively. The PAS estimates approximated 179 cm consistently across all grades. The estimates of PPAS consistently increased from 80% (4-5th grade) to 91% (8th grade).

Player sport participation and injury history. Questionnaires distributed to the parents at the beginning of the season (Appendix E) solicited information regarding each player's past sport participation and injury histories. Tables 8 through 12 report player sport participation data. Participants who have participated in the study for multiple years are presented in Table 8. Nearly half (45%) of the players were first year participants. Only 47 (6%) players have participated during all four years of observation. The low number of four-year participants is partially due to player attrition and only one of the two towns having 8th grade teams.

Over 75% of the players reported prior football experience (Table 9). Within the 4-5th grade group, over 64% reported having some form of football experience (includes flag football). Over 60% of the players reported playing between three and five sports annually, and 2% reported participating in seven sports annually (Table 10). The most common age at which the players reported beginning organized sports participation (Table 11) was five-years-old (43%). Soccer and tee ball were the most frequent first sport (32%, 33% respectively) as shown in Table 12.

Tables 13 through 16 summarize player reported previous injury data. The proportion of players who reported having a previous injury increased with each successive grade (Table 13). The 4-5th grade group had the lowest proportion of those reporting previous injury (18%) while the 8th grade had the highest (57%). The proportions of previously injured players who reported missing practices or games due to a previous injury decreased with each successive level of participation (Table 14). Of the

4-5th graders, 51% reported missing a practice or game due to injury while this proportion decreased to 40% for 8th graders. The ankle/foot (26%) followed by the wrist and hand (11%) were most common sites of reported previous injury (Table 15). Sprains and strains were the most frequent injury types accounting for 53% while general trauma such as contusions made up another 22% (Table 16). Fractures accounted for 13% of the injuries previously reported

Table 7

Mean Player and Parent Demographics by Grade

	4-5th Grade			6th Grade			7th Grade			8th Grade			All Grades		
Variable	n	M	SD	n	M	SD	n	M	SD	n	M	SD	N	M	SD
CA (yrs)	250	10.1	0.7	178	11.4	0.4	175	12.5	0.4	83	13.4	0.4	686	11.4	1.3
Stature (cm)	270	141.2	6.6	185	148.5	7.2	178	155.6	8.2	88	164.0	9.3	721	149.4	10.8
Weight (kg)	271	40.6	10.8	185	45.9	12.3	178	55.3	16.1	88	63.6	17.6	722	48.4	15.7
BMI (wt/ht^2)	270	20.2	4.2	185	20.6	4.3	178	22.5	5.0	88	23.3	4.7	721	21.2	4.7
PAS (cm)	228	178.5	6.3	160	178.9	6.1	165	179.0	6.0	82	180.8	6.7	635	179.0	6.2
PPAS (*P*)	228	79.2	2.4	160	83.1	2.3	165	86.9	2.8	82	90.8	2.7	635	83.7	4.8
Reported Dad Ht (cm)	251	180.4	7.9	178	180.2	8.2	175	180.1	7.1	83	180.7	7.1	687	180.3	7.7
Reported Mom Ht (cm)	254	165.3	7.2	178	165.0	6.7	175	165.0	6.3	83	165.9	6.2	690	165.2	6.7
Corrected Dad Ht (cm)	252	178.2	7.6	178	178.0	7.8	175	177.8	6.8	83	178.4	6.8	688	178.1	7.3
Corrected Mom Ht (cm)	254	164.6	6.8	178	164.4	6.4	175	164.1	6.0	83	165.2	5.9	690	164.6	6.4
MPS (cm)	253	171.1	8.0	178	171.2	5.2	175	171.1	4.9	83	171.8	4.9	689	171.2	6.3

Table 8

Proportion of Returning Players by Grade and Year in Study

	Grade									
	4-5th		6th		7th		8th		All Grades	
Year	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
1st	204	68.9	78	38.4	45	23.9	21	22.8	348	44.7
2nd	92	31.1	57	28.1	51	27.1	19	20.7	219	28.1
3rd	0	0.0	68	33.5	69	36.7	28	30.4	165	21.2
4th	0	0.0	0	0.0	23	12.2	24	26.1	47	6.0
Total	296	100.0	203	100.0	188	100.0	92	100.0	779	100.0

Table 9

Proportion of Participants with Prior Football Experience by Grade

	Grade									
Previous	4-5th		6th		7th		8th		All Grades	
Experience	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
No	90	35.7	37	21.1	28	16.7	13	15.3	168	24.7
Yes	162	64.3	138	78.9	140	83.3	72	84.7	512	75.3
Total	252	100.0	175	100.0	168	100.0	85	100.0	680	100.0

Table 10

Proportion of Players who Reported Playing Sports Other than Football by Grade

	Grade									
Number	4-5th		6th		7th		8th		All Grades	
of Sports	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
0	9	3.6	7	4.0	4	2.4	0	0.0	20	2.9
1	34	13.5	17	9.7	16	9.5	5	5.9	72	10.6
2	40	15.9	28	16.0	21	12.5	8	9.4	97	14.3
3	61	24.2	32	18.3	37	22.0	21	24.7	151	22.2
4	49	19.4	42	24.0	44	26.2	22	25.9	157	23.1
5	43	17.1	36	20.6	37	22.0	19	22.4	135	19.9
6	10	4.0	12	6.9	8	4.8	7	8.2	37	5.4
7	6	2.4	1	0.6	1	0.6	3	3.5	11	1.6
Total	252	100.0	175	100.0	168	100.0	85	100.0	680	100.0

Table 11

Proportion of the Ages that Participants Reported Beginning to Play Organized Sports by Grade

	Grade									
Age at	4-5th		6th		7th		8th		All Grades	
1st Sport	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
3	2	0.8	4	2.3	1	0.6	0	0	7	1.0
4	31	12.3	18	10.3	14	8.3	5	5.9	68	10.0
5	111	44.0	71	40.6	66	39.3	44	51.8	292	42.9
6	58	23.0	37	21.1	30	17.9	18	21.2	143	21.0
7	17	6.7	17	9.7	22	13.1	12	14.1	68	10.0
8	6	2.4	10	5.7	13	7.7	3	3.5	32	4.7
9	22	8.7	6	3.4	8	4.8	2	2.4	38	5.6
10	5	2.0	4	2.3	5	3.0	1	1.2	15	2.2
11	0	0	6	3.4	4	2.4	0	0	10	1.5
12	0	0	1	0.6	3	1.8	0	0	4	0.6
13	0	0	1	0.6	2	1.2	0	0	3	0.4
Total	252	100.0	175	100.0	168	100.0	85	100.0	680	100.0

Table 12

Proportion of First Sports Played as Reported by Participants by Grade

	Grade									
	4-5th		6th		7th		8th		All Grades	
Sport	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
Baseball	7	2.8	7	4.0	9	5.4	2	2.4	25	3.7
Basketball	6	2.4	10	5.7	14	8.3	2	2.4	32	4.7
Flag football	11	4.4	5	2.9	3	1.8	2	2.4	21	3.1
Floor hockey	16	6.3	6	3.4	6	3.6	7	8.2	35	5.1
Football	17	6.7	13	7.4	11	6.5	3	3.5	44	6.5
Hockey	9	3.6	5	2.9	3	1.8	1	1.2	18	2.6
Soccer	81	32.1	55	31.4	52	31.0	32	37.6	220	32.4
Softball	1	0.4	2	1.1	0	0.0	0	0.0	3	0.4
Swimming	3	1.2	3	1.7	1	0.6	0	0.0	7	1.0
Wrestling	15	6.0	9	5.1	10	6.0	1	1.2	35	5.1
Tee ball	84	33.3	58	33.1	53	31.5	32	37.6	227	33.4
Other	1	0.4	0	0.0	0	0.0	0	0.0	1	0.1
Gymnastics	1	0.4	1	0.6	2	1.2	1	1.2	5	0.7
Karate	0	0.0	1	0.6	3	1.8	2	2.4	6	0.9
Bowling	0	0.0	0	0.0	1	0.6	0	0.0	1	0.1
Total	252	100.0	175	100.0	168	100.0	85	100.0	680	100.0

Table 13

Proportion of Participants who reported having a Previous Injury by Grade

Previous	Grade									
	4-5th		6th		7th		8th		All Grades	
Injury	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
No	204	81.9	108	62.8	96	58.5	32	42.7	440	66.7
Yes	45	18.1	64	37.2	68	41.5	43	57.3	220	33.3
Total	249	100.0	172	100.0	164	100.0	75	100.0	660	100.0

Table 14

Proportion who Reported Missing Practices and Games Due to a Previous Injury by Grade

Previous	Grade									
	4-5th		6th		7th		8th		All Grades	
Injury	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
No	22	48.9	33	52.4	36	52.9	26	60.5	117	53.4
Yes	23	51.1	30	47.6	32	47.1	17	39.5	102	46.6
Total	45	100.0	63	100.0	68	100.0	43	100.0	219	100.0

Table 15

Proportion of Reported Previous Injury Locations by Grade

Previous	Grade									
	4-5th		6th		7th		8th		All Grades	
Injury	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
Head/neck	2	4.4	8	12.5	4	5.9	0	0.0	14	6.3
Face	2	4.4	3	4.7	0	0.0	0	0.0	5	2.3
Shoulder arm	5	11.1	7	10.9	7	10.3	5	11.4	24	10.9
Wrist/hand	6	13.3	10	15.6	13	19.1	8	18.2	37	16.7
Trunk	3	6.7	1	1.6	1	1.5	0	0.0	5	2.3
Hip/thigh/leg	4	8.9	3	4.7	2	2.9	2	4.5	11	5.0
Knee	2	4.4	7	10.9	7	10.3	3	6.8	19	8.6
Ankle/foot	11	24.4	17	26.6	19	27.9	11	25.0	58	26.2
Other	0	0.0	0	0.0	3	4.4	1	2.3	4	1.8
Multiple	10	22.2	7	10.9	12	17.6	14	31.8	43	19.5
Not specified	0	0.0	1	1.6	0	0.0	0	0.0	1	0.5
Total	45	100.0	64	100.0	68	100.0	44	100.0	221	100.0

Table 16

Frequency and Proportions of Reported Previous Injury Type by Grade

	Grade									
Previous	4-5th		6th		7th		8th		All Grades	
Injury	n	*P*	n	*P*	n	*P*	n	*P*	N	*P*
Sprain/strain	20	44.4	33	52.4	38	55.9	25	58.1	116	53.0
Fracture	6	13.3	8	12.7	9	13.2	5	11.6	28	12.8
Laceration	2	4.4	1	1.6	0	0.0	0	0.0	3	1.4
General	9	20.0	16	25.4	13	19.1	10	23.3	48	21.9
Combined	8	17.8	4	6.3	5	7.4	2	4.7	19	8.7
Other	0	0.0	0	0.0	2	2.9	1	2.3	3	1.4
Not specified	0	0.0	1	1.6	1	1.5	0	0.0	2	0.9
Total	45	100.0	63	100.0	68	100.0	43	100.0	219	100.0

Injury data analysis. Injury data were analyzed cumulatively and across grades. The player frequencies, injury incidence, athlete exposures, injury rates, and incidence density ratios are reported in Table 17. There were 779 players for all grades with 37% sustaining an injury. The 4-5th grade players had the least risk of injury (29%) while the 7th grade players had the highest (58%). The risks for 6th and 8th graders were 37% and 46% respectively.

There were 474 injuries and 26565 AE. Practices accounted for 69% of the injuries and 82% of the AE. Of the total injuries, 59% were classified as NTL. Injury rates were reported with 95% CI. Injury rates were calculated by dividing the number of injuries by the number of exposures and were expressed per 1000 AE. The overall injury rate was 17.8 (95% CI: 16.3, 19.4) per 1000 AE. The game injury rate was 30.5 (95% CI: 25.6, 35.4) and the practice injury rate was 15.1 (95% CI: 13.5, 16.7) per 1000 AE. The overall and practice injury rates increased with each succeeding grade, but the game injury rate was highest in the 6th grade players (35.3, 95% CI: 24.7, 45.9). Time-loss injury rates also increased with each succeeding grade but NTL injury rates were more variable.

Incidence density ratios (IDR) and 95% confidence intervals were calculated as described by Powell and Dompier (2004) to provide comparison between the injury rates for games and practices and between NTL and TL injuries. The data reveal that players were twice as likely to be injured in a game versus practice and that they were 1.4 times more likely to suffer a NTL injury than a TL injury. The incidence density ratios were similar across all grades for both comparisons except for the 8th graders. The IDR for 8th grade NTL versus TL injuries was 0.5 (95% CI: 0.2, 1.5). In summary, players had twice the risk of suffering a game related injury, and were 1.4 times more likely to suffer a NTL injury.

Intrinsic risk factor analysis. Player related intrinsic variables were analyzed by calculating relative risks for PPAS, stature, weight, BMI, previous injury, previous football experience, and prior injuries that were serious enough to cause time loss from participation. Variables identified as significant through univariate analysis were further scrutinized using backwards-stepwise logistic regression to control for confounding. Univariate and logistic regression analyses were performed and reported with the data both stratified and not stratified by grade to control for grade as a confounding variable. Stratification by grade was thought necessary because practices and games only occur between teams of the same grade level. Univariate analysis of grade when the 4-5th graders are the referent reveals that relative risk increases with each grade and 7th and 8th grade levels are close to being significantly more at risk than the 4-5th graders (Table 18).

Table 17

Summary of Injury Data by Grade

Item	4-5th	95% CI lower upper	6th	95% CI lower upper	7th	95% CI lower upper	8th	95% CI lower upper	Total	95% CI lower upper
Players	296		203		188		92		779	
Injured Players	87		76		110		43		284	
Exposures	9595		6674		6889		3407		26565	
Practice	7898		5512		5640		2757		21807	
Game	1697		1162		1249		650		4758	
Total Injuries	137		127		136		74		474	
TL	41		57		49		49		196	
NTL	96		70		87		25		278	
Practice	91		86		99		53		329	
Game	46		41		37		21		145	
Injury Rate	14.3	11.9, 16.7	19.0	15.8, 22.3	19.7	16.5, 23.0	21.7	16.8, 26.6	17.8	16.3, 19.4
TL	4.3	3.0, 5.6	8.5	6.3, 10.7	7.1	5.1, 9.1	14.4	10.4, 18.4	7.4	6.3, 8.4
NTL	10.0	8.0, 12.0	10.5	8.0, 12.9	12.6	10.0, 15.3	7.3	4.5, 10.2	10.5	9.2, 11.7
Practice	11.5	9.2, 13.9	15.6	12.3, 18.9	17.6	14.1, 21.0	19.2	14.1, 24.3	15.1	13.5, 16.7
Game	27.1	19.4, 34.8	35.3	24.7, 45.9	29.6	20.2, 39.0	32.3	18.7, 45.9	30.5	25.6, 35.4
IDR NTL/TL	2.3	1.8, 3.5	1.2	1.3, 1.7	1.8	1.5, 2.6	0.5	0.2, 1.5	1.4	1.2, 1.9
IDR Game/Px	2.4	1.8, 3.5	2.3	1.7, 3.4	1.7	1.5, 2.5	1.7	1.6, 2.6	2.0	1.5, 2.9

TL = Time-Loss NTL = Non-Time-Loss IR = Injury Rate per 1000 Athlete Exposures IDR = Incidence Density Ratio

Table 18

Relative Risk for Injury by Grade

			Grade	
Grade	n	cases	RR	95%CI
4-5th	346	137	Referent	
6th	254	127	1.3	0.9, 1.2
7th	246	136	1.4	1.0, 1.9
8th	123	74	1.5	1.0, 2.3

All intrinsic player-related variables were categorized. Within-grade z-scores were calculated for statute, weight, and BMI for half-year age groups. The z-scores for maturity were calculated using the means and standard deviations for PPAS provided by Bayer and Bayley (1959). Players were categorized into terciles based on their respective z-score within their respective grade level (Malina et al., 2002). A player who had a z-score less than –1.00 was considered in the lowest tercile while a player with a z-score of greater than 1.00 was in the highest tercile. All z-scores ranging from –1 to 1 were listed in the middle tercile. As an example, maturity was categorized as late ($z < -1.00$), average ($-0.1 \leq z \leq 1$), and early ($z > 1.00$). Once categorized, referents for each variable were selected based on hypotheses and previously reported risks.

To calculate relative risks within each category one of the tercile groups had to be selected as a referent. The maturity referent was the early maturity group because it was hypothesized that late maturing players were at greater risk of injury. Similar conventions were used for all variables. Univariate relative risks and logistic regression odds ratios with 95% CI for all grades combined are summarized in Table 19, and grade stratified results are summarized in Tables 20-23.

The variables found significant through univariate analysis for all grades combined were the average and tall stature groups (RR = 1.4, 95%CI: 1.0, 2.1 and RR =

1.7 95%CI: 1.0, 2.8 respectively) and previous injury (RR = 1.5, 95%CI: 1.1, 2.0). There is also a gradient effect for stature. Risk increased from the average (1.4) to the tall (1.7) groups. Although insignificant, this gradient effect is also present in the maturity, weight, and BMI relative risks (Table 19).

Univariate analysis after stratification by grade (Tables 20-23) revealed that only the 4-5th grade group had significant relative risks for average stature players (RR = 2.2, 95%CI: 1.0, 4.7) and those with previous injury (RR = 1.9, 95%CI: 1.1, 3.4). The gradient effect was still present when stratified by grade except in the stature variable for the 4-5th grade group. Variables found significant through univariate analysis, and the maturity variable were included in the logistic regression analysis. Maturity was not found to be significant through univariate analysis, but it was included during the logistic regression analysis because it was the variable of interest in this study.

The results of the backwards-stepwise logistic regression were consistent with the univariate analysis of risk factors. The results of a logistic regression are reported as an odds ratio, or the odds of one group developing the outcome versus another. Average and tall stature and previous injury remained significant in the final model for all grades combined (Table 19). Previous injury was not significant for grades 7th and 8th when stratified by grade (Tables 20-23). Only the 4-5th graders had significant odds ratios for both average (OR = 3.5, 95%CI: 1.5, 8.6) and tall (OR = 2.88, 95%CI: 1.0, 8.0) stature groups. Grades 6th and 7th had significant odds ratios for the tall group of the stature variable. The 8th grade group had no significant odds ratios in the final model. The 7th and 6th grades show a gradient effect of increasing risk for lower levels of maturity, but remain non-significant. The risk of late maturing 7th graders is 4.5 times higher (OR =

4.5, 95%CI: 0.92, 22.28) than that of an early maturing 7th grader, and is nearly significant.

In summary, stature and previous injury were significant risk factors for injury across all grades. There was also a gradient effect present for maturity, stature, weight, and BMI. Previous injury remained significant for 4-5th and 6th graders but not for 7th and 8th graders when stratified. None of the factors were significant for 8th graders during univariate or logistic regression analysis. Stature remained significant for 4-5th graders in both the average and tall groups, but only the tall group in grades 6th and 7th.

Table 19

Risk Factors for Injury in Youth Football Players: All Grades Combined

Risk factor	No. of players	No. of cases	Estimated RR	95% CI	Estimated OR	95% CI
Maturity						
Late	48	25	0.87	0.47, 1.62	1.61	0.55, 2.46
Average	519	252	0.81	0.59, 1.11	0.88	0.61, 1.26
Early	235	141	Referent		Referent	
Stature						
Short	127	45	Referent		Referent	
Average	623	315	1.43	0.96, 2.12	1.93	1.24, 3.01
Tall	147	88	1.69	1.03, 2.76	3.46	1.98, 6.04
Weight						
Low	97	47	Referent			
Average	660	318	0.99	0.65, 1.52		
Heavy	141	82	1.20	0.71, 2.02		
BMI						
Low	90	41	Referent			
Average	643	313	1.07	0.69, 1.66		
Heavy	162	92	1.25	0.74, 2.09		
Prev. injury						
Yes	302	195	1.51	1.13, 2.03	2.69	1.97, 3.69
No	525	224	Referent		Referent	
Prev. experience						
Yes	637	325	Referent			
No	213	104	0.96	0.70, 1.31		
Prev. injury caused time-loss						
Yes	146	102	1.19	0.74, 1.92		
No	153	90	Referent			

RR = Relative Risk   OR = Odds Ratio

Table 20

Risk Factors for Injury in Youth Football Players: 4^{th}-5^{th} grades

Risk factor	No. of players	No. of cases	Estimated RR	95% CI	Estimated OR	95% CI
Maturity						
Late	15	3	0.45	0.11, 1.78	0.53	0.11, 2.49
Average	202	93	1.04	0.57, 1.89	1.60	0.79, 3.24
Early	54	24	Referent		Referent	
Stature						
Short	44	9	Referent		Referent	
Average	216	96	2.17	1.00, 4.74	3.53	1.45, 8.59
Tall	54	23	2.08	0.84, 5.17	2.88	1.03, 8.04
Weight						
Low	27	6	Referent			
Average	243	100	1.85	0.72, 4.75		
Heavy	48	24	2.25	0.77, 6.55		
BMI						
Low	27	6	Referent			
Average	241	101	1.89	0.73, 4.84		
Heavy	47	22	2.11	0.72, 6.16		
Prev. injury						
Yes	70	48	1.93	1.09, 3.41	4.19	2.21, 7.96
No	228	81	Referent		Referent	
Prev. experience						
Yes	196	87	Referent			
No	105	43	0.92	0.57, 1.49		
Prev. injury caused time-loss						
Yes	42	33	1.47	0.52, 4.18		
No	28	15	Referent			

RR = Relative Risk OR = Odds Ratio

Table 21

Risk Factors for Injury in Youth Football Players: 6th grade

Risk factor	No. of players	No. of cases	Estimated RR	95% CI	Estimated OR	95% CI
Maturity						
Late	18	11	0.89	0.29, 2.70	0.95	0.24, 3.75
Average	133	59	0.65	0.33, 1.26	0.46	0.22, 0.96
Early	54	37	Referent		Referent	
Stature						
Short	33	13	Referent		Referent	
Average	166	81	1.24	0.58, 2.65	1.82	0.65, 5.11
Tall	37	27	1.85	0.68, 5.07	6.07	1.63, 22.59
Weight						
Low	22	9	Referent			
Average	180	93	1.26	0.51, 3.10		
Heavy	33	18	1.33	0.45, 3.97		
BMI						
Low	25	12	Referent			
Average	166	85	1.07	0.46, 2.47		
Heavy	42	22	1.09	0.41, 2.94		
Prev. injury						
Yes	84	51	1.38	0.79, 2.41	2.24	1.17, 4.29
No	132	58	Referent		Referent	
Prev. experience						
Yes	172	88	Referent			
No	47	22	0.92	0.57, 1.49		
Prev. injury caused time-loss						
Yes	42	29	1.29	0.52, 3.16		
No	22	41	Referent			

RR = Relative Risk   OR = Odds Ratio

Table 22

Risk Factors for Injury in Youth Football Players: 7th grade

Risk factor	No. of players	No. of cases	Estimated RR	95% CI	Estimated OR	95% CI
Maturity						
Late	15	11	1.24	0.36, 4.25	4.45	0.92, 22.28
Average	120	61	0.86	0.48, 1.53	0.95	0.49, 1.85
Early	78	46	Referent		Referent	
Stature						
Short	33	15	Referent		Referent	
Average	160	87	1.20	0.56, 2.54	2.25	0.78, 6.43
Tall	35	23	1.45	0.54, 3.84	5.58	1.36, 22.86
Weight						
Low	34	22	Referent			
Average	160	82	0.79	0.37, 1.71		
Heavy	35	21	0.93	0.35, 2.46		
BMI						
Low	24	15	Referent			
Average	162	84	0.83	0.34, 2.00		
Heavy	42	25	0.95	0.34, 2.67		
Prev. injury						
Yes	89	54	1.38	0.79, 2.41	1.73	0.95, 3.14
No	120	58	Referent		Referent	
Prev. experience						
Yes	175	93	Referent			
No	39	22	0.92	0.57, 1.49		
Prev. injury caused time-loss						
Yes	40	23	1.29	0.52, 3.16		
No	49	31	Referent			

RR = Relative Risk OR = Odds Ratio

Table 23

Risk Factors for Injury in Youth Football Players: 8th grade

Risk factor	No. of players	No. of cases	Estimated RR	95% CI	Estimated OR	95% CI
Maturity						
Late	0	0				
Average	64	39	0.88	0.40, 1.93	1.06	0.38, 3.00
Early	49	34	Referent		Referent	
Stature						
Short	17	8	Referent		Referent	
Average	81	51	1.34	0.47, 3.84	1.62	0.49, 5.41
Tall	21	15	1.52	0.40, 5.81	3.34	0.70, 16.00
Weight						
Low	14	10	Referent			
Average	77	43	0.78	0.23, 2.71		
Heavy	25	19	1.06	0.24, 4.67		
BMI						
Low	14	8	Referent			
Average	74	43	1.02	0.32, 3.23		
Heavy	31	23	1.30	0.34, 4.91		
Prev. injury						
Yes	59	42	1.19	0.52, 2.70	1.62	0.70, 3.71
No	45	27	Referent		Referent	
Prev. experience						
Yes	94	57	Referent			
No	22	17	1.27	0.43, 3.75		
Prev. injury caused time-loss						
Yes	22	17	1.23	0.37, 4.12		
No	35	22	Referent			

RR = Relative Risk   OR = Odds Ratio

Chapter Five

Discussion

The study consisted of two distinct stages of data collection and analysis. The first stage was designed to test the validity of the Khamis and Roche [KR](1994) method of adult stature prediction and subsequent percent of predicted adult stature as a method of maturity estimation. Stage two consisted of analyses of injury incidence, risk, rates, and intrinsic risk factors.

Stage One: The Validity of Percent of Predicted Adult Stature as a Maturity Indicator

Subsample baseline data. It was hypothesized that the noninvasive KR method of adult stature prediction is a valid method of estimating maturity when expressed as a percent of the child's predicted adult stature. The KR estimates were compared to those derived using the Khamis and Guo [RWT-KG](1993) method in a sample of youth football players between the ages of 9 and 14 years. The RWT-KG method is invasive because it requires an x-ray to determine skeletal age (SA), but is considered more accurate than estimates lacking SA (Khamis and Roche, 1994). To date, no reported studies have examined this relationship in a group of youth football players.

Overall, the subsample (n = 64) was slightly advanced in skeletal maturity. The average deviation between SA and chronological age (CA) was 0.7 years. Mean statures and weights were compared to the CDC Growth Charts for boys 2 to 20 for stature-for-age and weight-for-age (Ogden, Kuczmarski, Flegal, Mei, Guo, et al., 2002). In reference to stature, mean statures were between the 50th and 75th percentiles for all grades. The mean weights of all groups were between the 75th and the 90th percentiles for the corresponding mean age. These findings are consistent with the sample being advanced in skeletal maturity.

Maturity and size variation among football players has been previously reported. Malina, Meleski, and Shoup (1982) reported on anthropometric measurements and maturity estimates in youth football players taken in 1970. Malina et al. (1982) found that stature was near the United States median, but weight was just below the 75th percentile. Although the more weight-for-stature relationship is consistent between this study and that reported by Malina et al., the results of the current study show a drastic increase in the percentiles in the 33 years between studies. This difference could be the result of many factors such as taller statures, increased obesity, or increased muscle mass as the result of early ages at which children begin weight training. Body fat percentages were not considered in this study.

Subsample statistical analysis. Analysis of the subsample data demonstrates a moderate but statistically significant correlation between the KR percent of predicted adult stature and SA (partial r, adjusted for CA, = 0.54; $p < .001$). The mean estimates of predicted adult statures derived from the RWT-KG and KR methods were statistically different ($t(63) = 2.29$, $p < .05$), but highly correlated (partial r, adjusted for CA, = 0.88; $p < .001$). This finding is consistent with the findings reported by Khamis and Roche (1994) and demonstrates that the non-invasive KR method is a useful proxy when SA is unavailable. Thus, the use of percent of predicted adult stature was a useful tool in differentiating between those of varying maturity status in the current study. The application of the KR percent of predicted adult stature as a maturity estimate is recommended when skeletal age is contraindicated or unavailable, and sample ages range between 3 and 17.5 years of age.

The strong correlations between the RWT-KG and KR methods of adult stature prediction found in the current study are consistent with other published comparisons. Khamis and Roche (1994) compared estimates for males and females using both methods. Comparison of estimates in males showed a slightly larger 90% error bound (2.1) when SA is omitted (KR method) than when it is included (1.8 cm) as in the RWT-KG model. Estimates in females were 1.7 cm when SA was omitted (KR), and 1.5 cm with SA (RWT-KG). Zarow (1997) found similar results, but both methods produced higher mean errors than those reported by Khamis and Roche (1994). This difference is likely the result of the difference between the reference population and the population sampled by Zarow. The results of the current study indicate that the percentage of predicted adult stature derived from the KR method of adult stature prediction is a valid estimate of maturity and can be a useful tool in field studies where invasive methods of maturity estimation are impractical or contraindicated. These recommendations are limited to youth football players between the ages of 9 and 14 years of age.

Stage Two: Injury Analysis

Baseline data and maturity estimation. Measurements of stature, weight, and BMI for the entire study population were reported for each grade in Table 7. The current study means were compared to national averages (Appendices G-J) using the CDC Growth Charts for boys 2 to 20 for stature-for-age, weight-for-age, and BMI-for-age percentiles (Ogden et al., 2002). Mean ages that were compared to the growth charts were 10, 11.4, 12.5, and 13.5 for the 4-5th, 6th, 7th, and 8th grades respectively. For all ages, stature was between the 50th and 75th percentiles with the 4-5th and 7th grades nearly equal to the 75th percentile. Weight and BMI were closer to the 90th percentile for all grades. These comparisons would indicate that the current sample is on average, slightly taller, but much heavier than the majority of children in the United States of the same age. National averages for PPAS do not exist, but comparisons can be made with means of PPAS reported by Bayer and Bayley (1959).

Bayer and Bayley (1959) produced means of percents of predicted adult statures (PPAS) for ages 3 to 18 years with data from the Berkley Growth Study (Bayley and Pinneau, 1953). On average, the children of the current study had higher mean PPAS as compared to those reported by Bayer and Bayley, indicating that the current sample is on average more mature (Appendix J). This finding may indicate that the assignment of terciles of maturity status was biased. Assignment to terciles of maturity in the current study followed the methods reported by Malina et al. (2002). Because the current population was on average more mature, the z-scores would also drift toward a tercile of higher maturity. It is possible that this effect reduced the number of participants listed in the lower two terciles of maturity and increased the likelihood of not finding a significant relative risk for maturity in the average and late maturing.

Injury analysis. The incidence of injury reported in the current study is consistent with previous reports involving junior high school and youth football players. Table 1 summarizes previous studies that report injury risks that range from 6% (Stuart et al., 2002) to 51% (Radelet et al., 2002). The injury risk in the current study was 37%, and is equal to the risk reported by Violette (1976). Injury risk varies according to injury definition and the data source. The ATC data collector and injury definition used in the current study is more sensitive than that used by Stuart el al. because the current definition included every injury evaluated by an ATC. The definition used by Stuart et al. required that the player be removed from play or required advanced medical procedures or evaluation. In addition, Stuart utilized physicians as data collectors who were only present at competitions. Tuberville et al. (2003a) used a similar time-loss definition, and utilized ATCs to collect injury data. Even with the increased sensitivity of an ATC data collector, Tuberville et al. reported a 10% incidence which is lower than those found in the current study. Similar trends are evident when injury rates are compared.

The current overall injury rate was over twice as high as those previously reported for youth football players. The difference in the current study is due to the increased sensitivity of the injury definition that included NTL injuries. When the injury rates were dichotomized into TL and NTL injuries, the TL injury rate (7.4, 95%CI: 6.3, 8.4 per 1000 AE) was similar to that reported by Powell and Barber-Foss (1999) for high school football players (8.1 per 1000 AE). In addition, the current TL injury rate of 7.4 is also similar to that reported by Powell and Dompier (2004) (9.8) who examined both TL and NTL injuries in college football players. The NTL injury rates were not as similar however. The NTL injury rate was 10.5 (95%CI: 9.2, 11.7) or about one third of that reported by Powell and Dompier (30.8).

Injuries that are defined as non-time-loss are important to consider because of the impact that they have on players, coaches, and parents. The results of the current study demonstrate that only 40% of the injuries that require a decision regarding the playing status of injured players have been previously reported. This suggests that the coach or a parent has to make a decision regarding the playing status of that child. This is concerning because previous injury has been reported as a risk factor for injury. If appropriate decisions are not made regarding the disposition of an injured athlete, they could be potentially put at risk by being returned to play while recovering from a previous injury. Providing coaches and or parents with basic first aid skills may help to mitigate this risk.

Intrinsic risk factor analysis. Risk factor analysis was limited to player intrinsic factors. This limitation was primarily due to inadequacies in study design, but also partially due to uncontrollable factors. Specific player positions have been shown to be risk factors for injury in previous studies (Beachy et al., 1996; Blyth and Mueller, 1974; Powell, 1980; Powell and Schootman, 1992; Turbeville et al., 2003a), but were untraceable in the current study. Players were not specialized to any one specific position and often played multiple different positions during any single session. Although players were asked what positions they were playing at the time of injury, positions of uninjured players were not known. Therefore, no comparison can be made between injured and uninjured in respect to player position. Additionally, environmental conditions were not systematically reported therefore no comparisons could be made between surface conditions. Previous studies have implicated weather related playing surface conditions and the shoe-surface interface as risk factors (Bramwell, et al., 1972; Orchard, 2002; Orchard and Powell, 2003; Powell and Schootman, 1992; Torg and Quedenfeld, 1971). These limitations restricted the risk factor analysis in the current study to player intrinsic variables.

Player intrinsic variables have been implicated as risk factors for injury in youth and junior high school football players (Caine and Broekhoff, 1987; Gomez et al., 1998; Linder et al., 1995; Malina et al., 2002; Turbeville, 2003a, Violette, 1979). Variables that have been studied include stature, weight, BMI, previous injury, previous experience, grip strength, and maturity. Findings among the different variables are inconsistent and comparisons of maturity are made difficult because of inconsistent methods. The current study examined maturity, stature, weight, BMI, previous injury, previous experience, and previous injuries that caused time-loss. Of those, only stature and previous injury were found to be significant even though maturity was the variable of interest.

Maturity was the intrinsic variable of interest in the current study, but found to be non-significant. Late maturity status has been implicated as a risk factor for injury in children who play sports with children of the same age or grade, but are of higher maturity status (Linder et al., 1995; Malina et al., 2002; Violette, 1979). Linder et al. found that those in higher Tanner stages were more at risk of injury, but Malina et al. found no relationship. Conversely, Violette found that those who were late maturing were at greater risk. The results of the current study cannot clarify this disparity because no significant relationships were found. However, even though no significant relative risks were found for maturity status and injury, there is an increasing gradient effect with higher maturity status. This gradient effect would support the findings by Linder et al. in that as maturity status increased, a concurrent increase was seen in the relative risk (Tables 19-22).

Many plausible explanations exist for the differences found between studies examining maturity status as a risk factor for injury in youth football players. In the current study, exposure was not adequately controlled. A team level of exposure was collected, meaning that those present at each session were counted as one AE. Dagiau et al. (1980) demonstrated that time of exposure can bias risk factor analysis in football because not all players receive equal playing time in competitions or equal repetitions in practice. To determine if maturity is a risk factor, a player level exposure is necessary. The player level of exposure is the specific number of repetitions or playing minutes each player receives during practice or competitions. Analyses would then stratify or otherwise control for playing time between those who are injured and those who are not. If late maturity were a risk factor for injury in the current study, then the exposure bias could have prevented it from being detected.

The nature of the population could also be a reason why maturity was not detected as a risk factor. Because this sample of youth football players was, on average, more mature than the reference population (Bayer and Bayley, 1959), fewer subjects would be classified in the lower terciles of maturity therefore the groupings may be biased. This bias would reduce the frequencies in the lower terciles and would prevent detection of a difference. Another reason might simply be that there really is no difference in injury risk between those of later and those of earlier maturity status. Finally, there may have been systematic flaw in the prediction of maturity or in the method used to categorize maturity groups. There are similar disparities when comparing other intrinsic variables.

There is no consensus on which intrinsic risk factors for injury are the most important in youth football. Gomez et al. (1998) found that body fatness and BMI were significant risk factors for injury. Malina et al. (2002) found that stature and previous injury were significant risk factors. Turbeville et al. (2003a) found that previous experience was a risk factor. The current findings that stature and previous injury are significant risk factors are in agreement with Malina et al. (2002). The agreement with Malina et al. is expected however, because the current study is a continuation of the original. Although non-significant, previous experience was in agreement with Turbeville et al. (2003a), and weight was in agreement with Gomez et al. Weight demonstrated an increasing gradient effect on the relative risk for the average and heavy groups (Tables 19-22). The only similarity between these studies and the current was that the results of each were likely confounded by player exposure bias.

Player exposure bias may not be the only bias to affect the stature, weight, and BMI variables. As noted above, the study sample was on average more mature, taller (75^{th} percentile), and heaver (90^{th} percentile) than national means. This difference likely caused less frequencies in the lower two terciles in each of those variables. If the current means were closer to national estimates, a greater difference may have been found. This bias should be tempered for stature, weight, and BMI because z-scores were based on the sample mean, not a national mean. Intrinsic variables are not the only variables that may have been biased and Malina et al. (2002) have reported that there are inherent differences between the 4-5^{th}-6, and 7^{th}-8^{th} grade teams.

The classification of players by grade in which they play may not have adequately represented the sport. In grades 4-5^{th} and 6^{th}, the rules do not allow kicking plays (punts, kick-offs, and field goals). The 7^{th} and 8^{th} grade teams follow the same rules as the local high school teams do, and allow all types of play situations. Statistical analyses of the data by kicking exposure would have added power and more adequately represented the type of game played. Univariate analysis between no-kicking and kicking dichotomies reveals that the kicking group (7^{th}-8^{th} grades) is at greater risk of injury (RR = 1.29, 95%CI: 1.0-1.7). Future analyses should seek to control for kicking as a possible confounder.

Conclusions

The non-invasive KR method of predicted adult stature is a valid estimate of maturity when current stature is expressed as a percentage of predicted adult stature. Injury incidence, risk, and injury rates are within previously reported ranges. Non-time-loss injuries accounted for 59% of the total injury picture, and these findings are consistent with previously reported NTL injury risk. Maturity is not a risk factor for injury, but stature and previous injury are. All intrinsic variables may be biased by exposure time and the anthropometric characteristics of the sample. Additional research should focus on the player level of exposure versus the team or sport levels of exposure. Without adequately controlling for exposure, it will not be possible to determine if those who are late maturing are at greater risk of injury when playing with children their same age but of higher maturity status.

Future Research

The issue of matching competitors by maturity, age, or skill remains unresolved. Before recommendations to match competitors by maturity can be made, research must definitively demonstrate that maturity is related to injury risk. Maturity and other intrinsic variables can only be analyzed if exposures are reported at the player level. Controlling for the player level of exposure could be accomplished by reporting the number of plays each player participates in during games, or the number of minutes each is on the field. Practice exposures are more difficult to control however, and would require careful scrutiny of what type of drill and how much each player is involved.

The case control design is another method to control for exposure. When using a control design, at the time that an injury occurs, random selection of up to four other players who were on the field at the same would allow comparison of both sport and player level variables. A case control design would also mitigate the difficulty tracking practice activities because it would only be necessary to document the activities of the injured player and the four controls at the time of injury. One drawback of the case control design is that time order cannot be determined in most studies. This weakness is also mitigated by documenting the cases and controls at the time of injury because time order will be known. The case control design would be a powerful tool if applied to sports injury research.

This study has shown that maturity can be estimated by determining the percent of adult stature that a child has attained. There are multiple options choose from when determining how to apply the estimates derived from this procedure. The percent of predicted adult stature is a continuous variable and can be analyzed using numerical methods, or it can be converted into a categorical variable and analyzed using categorical procedures as demonstrated in this study. Although the external validity of the current results are limited to Caucasian youth football players from rural and suburban communities, it is the opinion of this author that percent of predicted adult stature could be applied in a variety of setting where other methods of maturity estimation are unavailable.

Appendix A

Relationships Among Player Risk Factors and Injuries in Youth Football
Parental Informed Consent Form
(Injury Surveillance and Surveys)

For questions regarding this study, please contact:
John W. Powell, PhD, ATC
Principle Investigator
Department of Kinesiology
Michigan State University
105 IM Circle
East Lansing, MI 48824
517-432-5018

For questions regarding your rights as a research participant, please contact:
Ashir Kumar, MD
Chair Person
Committee on Research Involving Humans
Michigan State University
202 Old Hall
East Lansing, MI 48824
517-355-2180

Dear Parents & Guardians:

Hello! My Name is John W. Powell, PhD, ATC, Assistant Professor of Kinesiology and Certified Athletic Trainer at Michigan State University. Thomas Dompier, ATC and Mary Barron, ATC, and I are working on a research study entitled, "Relationships Among Player Risk Factors and Injuries in Youth Football." This year will be the 4th year of the project, and the first year that the project will be funded with a grant from the National Football League Charities (NFL). The continuation of this study allows us to provide athletic training services for the junior football team your child is participating on. Dr. Jeff Kovan, The Director of Sports Medicine at MSU, is also a consultant on the project. The study will continue to monitor injury patterns in youth football and the relationship between maturity status and players' perception of risk.

The study will involve your child's participation throughout the football season. At the beginning of the season we will measure your child's height and weight. Height and weight will be measured as part of equipment handout process and will take less than 10 minutes. At the end of the season we will ask them to complete a questionnaire designed to learn more about their thoughts regarding injury risk in football. This questionnaire usually takes about 10 minutes to complete, and will be conducted during practice time. Included with this consent form is a questionnaire regarding your child's previous experience in youth sports and if and what type of injuries they might have had. This questionnaire should also takes about 10 minutes or less to complete. Additionally, at the end of the questionnaire, we ask that you provide the heights of both biological parents. In total, we ask for about 20-30 minutes of your child's and your time to complete this form and the questionnaires.

The height of your child plus the heights of both biologic parents allows us to estimate your child's maturity status. We can then compare the maturity status of players to the injury rates for each age group to determine if maturity is a factor for injury.

Throughout the season, the Certified Athletic Trainer assigned to your child's team will document information concerning injuries that occur during practices and games. This information will include the severity, type of injury, the position played, activity performing when hurt, etc. Additionally, with your permission, we may discuss the injury with your child, and or contact you by phone to obtain additional information about the injury.

All identities and recorded information collected during this study will remain confidential and will be replaced and analyzed with individual identification numbers. Participants will remain anonymous in any reporting of the data from this study, and your privacy will be protected to the maximum extent allowable by law.

In order for us to allow your child to participate in the study, we will need your written consent in the spaces provided below. Your child's participation is voluntary and you or your child may discontinue their participation at any time. If your child's participation is discontinued, their data will not be used in our study.

Any questions concerning participation in this study should be directed to John W. Powell, Assistant Professor of Kinesiology (517) 432-5018. If you have any additional questions concerning your child's rights in this research study, please feel free to contact Ashir Kumar, MD, Michigan State University's chair of the Committee on Research Involving Human Subjects at (517) 355-2180.

INFORMED CONSENT:
This section indicates that you are giving your informed consent.

I have read and agree to allow my child, ______________________________
Please Print Your Child's Name
to participate in this study as described above.

____
Please Print Your Name

______________________________ ____/____/____
Your Signature *Date*

Appendix B

Relationships Among Player Risk Factors and Injuries in Youth Football
Participant Informed Consent Form
(Injury Surveillance and Surveys)

For questions regarding this study, please contact:
John W. Powell, PhD, ATC
Principle Investigator
Department of Kinesiology
Michigan State University
105 IM Circle
East Lansing, MI 48824
517-432-5018

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Ashir Kumar, MD
Chair Person
Committee on Research Involving Humans
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202 Old Hall
East Lansing, MI 48824
517-355-2180

This study is designed to assess the thoughts you have concerning being injured when playing sports. This study will help us understand the things that might lead to injury in youth football.

For this study, you will be asked to complete a questionnaire regarding your thoughts on being injured in youth football. This questionnaire will take about 10 minutes to complete and you will have time during practice to complete it. We will also measure your height and weight at the beginning of the season during equipment handout. Also, a certified athletic trainer will record information about injuries you may have throughout the season. If you are injured, we will ask you additional questions like how it happened and what position you were playing.

All the information you provide, and the results of the study will be confidential and anonymously reported. You will be assigned a coded identification number that will be used on all information you provide. All the questionnaires and information you provide will be stored in a locked file cabinet inside a locked office that is accessible only to the investigators of this project. Only group data will be reported and group data will be provided to you at your request. Your participation in this study is voluntary. You may choose to quit and refuse to answer any questions at any time without penalty. Your information will remain anonymous in any reporting of the data from this study, and your privacy will be protected to the maximum extent allowable by law.

Any questions you may have concerning your participation in this study should be directed to Dr. John W. Powell at the Department of Kinesiology at Michigan State University, 517-432-5018. If you have additional questions or concerns about your rights in this research study, please feel free to contact Ashir Kumar, MD, Michigan State University's Chair of the Committee on Research Involving Human Subjects at 517-355-2180.

Thank you for you time and cooperation.

I have read or have had read to me, the above description of the study and agree to participate.

Please Print Your Name:____
First Name　　Middle Initial　　First Name

______________________________　　　　________________________
Sign Name Here　　　　Date

Appendix C

Relationships Among Player Risk Factors and Injuries in Youth Football

Parental Informed Consent Form
(X-ray Maturity Analysis)

For questions regarding this study, please contact:
John W. Powell, PhD, ATC
Principle Investigator
Department of Kinesiology
Michigan State University
105 IM Circle
East Lansing, MI 48824
517-432-5018

For questions regarding your rights as a research participant, please contact:
Ashir Kumar, MD
Chair Person
Committee on Research Involving Humans
Michigan State University
202 Old Hall
East Lansing, MI 48824
517-355-2180

Dear Parents & Guardians:

Hello! My Name is John W. Powell, PhD, ATC, Assistant Professor of Kinesiology and Certified Athletic Trainer at Michigan State University. Thomas Dompier, ATC and Mary Barron, ATC, and I are working on a research study entitled, "Relationships Among Player Risk Factors and Injuries in Youth Football." This year will be the 4th year of the project, and the first year that the project will be funded with a grant from the National Football League Charities (NFL). The continuation of this study allows us to provide athletic training services for the junior football team your son is participating on. Dr. Jeff Kovan, The Director of Sports Medicine at MSU, is also a consultant on the x-ray portion of the project. The study will continue to monitor injury patterns in youth football and the relationship between maturity status and players' perception of risk.

You have received this informed consent if you have volunteered to participate in the x-ray portion of the study. This portion of the study will involve taking one x-ray of your son's left hand. The single left hand x-ray is the most accurate method of estimating your son's skeletal age. This estimate allows us to estimate your son's predicted adult height. We will compare this information to the non-invasive method of estimating predicted adult height that is based on your son's current height, age, and heights of the biological parents. It is important that we validate our non-invasive method of estimating the maturity of children so in future studies researchers can use the non-invasive method with a reasonable degree of certainty. You will be provided with the individual results of your son's estimate.

The x-ray may require that your son miss an evening practice. You will be asked to transport your son to the medical facility nearest your city that has volunteered to assist in the study. You will be scheduled for a specific time, and given a week notice before your scheduled x-ray date. You will not be charged for the x-ray. The grant provided by the NFL Charities will pay for the single left hand x-ray for each participant. This process may take up to 1 hour typically and in rare situations more than an hour depending on emergencies and the like that may be brought into that medical facility. This hour includes driving time to and from the facility.

Your son will be minimally exposed to radiation, but all customary safeguards will be used to limit this exposure. This is less exposure than most diagnostic x-ray visits because we are asking for only one x-ray versus the multiple x-rays that are often taken for diagnostic purposes.

All identities and recorded information collected during this study will remain confidential and will be replaced and analyzed with individual identification numbers.
Participants will remain anonymous in any reporting of the data from this study, and your privacy will be protected to the maximum extent allowable by law.

In order for us to allow your son to participate in the study, we will need your written consent in the spaces provided below. Your son's participation is voluntary and you or your son may discontinue their participation at any time. If your son's participation is discontinued, their data will not be used in our study.

Any questions concerning participation in this study should be directed to John W. Powell, Assistant Professor of Kinesiology (517) 432-5018. If you have any additional questions concerning your son's rights in this research study, please feel free to contact Ashir Kumar, MD, Michigan State University's chair of the Committee on Research Involving Human Subjects at (517) 355-2180.

INFORMED CONSENT:
This section indicates that you are giving your informed consent.

I have read and agree to allow my child, ______________________________
Please Print Your Child's Name
to participate in this study as described above.

____
Please Print Your Name

________________________   ____/____/____
Your Signature   *Date*

Appendix D

Relationships Among Player Risk Factors and Injuries in Youth Football

Participant Informed Consent Form
(X-ray Estimate)

For questions regarding this study, please contact:
John W. Powell, PhD, ATC
Principle Investigator
Department of Kinesiology
Michigan State University
105 IM Circle
East Lansing, MI 48824
517-432-5018

For questions regarding your rights as a research participant, please contact:
Ashir Kumar, MD
Chair Person
Committee on Research Involving Humans
Michigan State University
202 Old Hall
East Lansing, MI 48824
517-355-2180

This study is designed to compare to two methods that determine how tall you may become as an adult. Your participation in this study will allow future researchers to use the non-invasive method of comparing your current height with the average of your parents' heights.

For this study, you will be asked to provide a single left hand x-ray. This will require that you possibly miss one day of practice. You will be exposed to a very small amount of radiation, but all efforts will be made to reduce this amount. The amount you will be exposed to will be less than is typically required if getting an x-ray to find broken bones. This process may take up to a hour or longer to complete.

Your information will remain anonymous in any reporting of the data from this study, and your privacy will be protected to the maximum extent allowable by law. You will be assigned a coded identification number that will be used on all information you provide. Only group data will be reported and group data will be provided to you at your request.

Your participation in this study is voluntary. You may choose to quit and refuse to answer any questions at any time without penalty. Any questions you may have concerning your participation in this study should be directed to Dr. John W. Powell at the Department of Kinesiology at Michigan State University, 517-432-5018. If you have additional questions or concerns about your rights in this research study, please feel free to contact Ashir Kumar, MD, Michigan State University's Chair of the Committee on Research Involving Human Subjects at 517-355-2180.

Thank you for you time and cooperation.

I have read or have had read to me, the above description of the study and agree to participate.

Please Print Your Name:____
First Name Middle Initial First Name

___________________________ ______________________
Sign Name Here Date

Appendix E

Background in Sports Information 2002-2003

Child's Name:________________________________ Team? 4^{th}-5^{th} 6^{th} 7^{th} 8^{th}
First Last

Date of Birth: _____/_____/______

Today's Date: _____/_____/______

How old was your child when he/she began to play on an organized sports team that practiced and played a regular schedule of games or competitions? Organized sports means that there was an assigned coach for the team. Examples include swimming, t-ball, football, basketball, etc.

______________ years old.

What was the first organized sport that your child played?______________Years played?_____

What other organized sports has your son/daughter played and how many years has he played each?

SPORT? YEARS PLAYED?

____

____

____

____

____

____

In evaluating the height and weight of your child, it is important to know the size of the biological parents. Please report the height of both biological parents to the nearest ¼ inch without shoes.

Father's Height______________

Mother's Height_____________

Has your child ever been injured during a sport practice or during a game/competition?

YES NO (please circle) If YES, please list the one or two most serious injuries and answer the questions:

INJURY ONE

a. What specific body part was injured?

Head/Neck Face Shoulder/Arm Forearm/wrist/hand

Trunk Hip/thigh/leg Knee Ankle/foot Other

b. What type of injury was it?

Sprain/strain Fracture Laceration General Trauma (bruise etc)

c. Did your child receive treatment? YES NO If yes, was he treated at:

An Emergency Room	YES	NO
A Doctor's Office	YES	NO
At Home	YES	NO

c. *Did your child miss any games, competitions or practices due to this injury?*

YES NO

INJURY TWO

a. What specific body part was injured?

Head/Neck Face Shoulder/Arm Forearm/wrist/hand

Trunk Hip/thigh/leg Knee Ankle/foot Other

b. What type of injury was it?

Sprain/strain Fracture Laceration General Trauma (bruise etc)

c. Did your child receive treatment? YES NO If yes, was he treated at:

An Emergency Room	YES	NO
A Doctor's Office	YES	NO
At Home	YES	NO

c. *Did your child miss any games, competitions or practices due to this injury?*

YES NO

Appendix F

Injury Report Form

NAME:______________________________ Date:_______________

Athletic Session

Game: Warm-up 1st Quarter 2nd Quarter 3rd Quarter 4th Quarter

Practice:

Position of Injured Player: Offense:__________________Defense______________

Type of Surface ________________Natural ___________________Artificial

Surface Condition ________Dry _______Wet _______Muddy _____Frozen

Weather Conditions: ____Hot ___Warm ___Cool ___Cold ___Rain ___Snow

Point in the Season________________________________

Action Taken:
_____Removed from participation and returned immediately
_____Returned from participation after resting
_____Removed from remainder of participation
_____Taken to hospital by parent
_____Taken to hospital by ambulance

Clinical Impression:
Injured Part of Body:

Head	Neck	Shoulder	Upper arm		Elbow	Forearm	Hand	Wrist	Fingers
Hip	Thigh	Knee	Shin	Calf	Ankle			Foot	Toes
Back	Abdomen		Chest	Other					

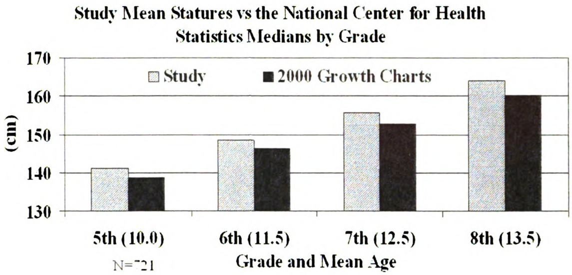
Type of Injury:

Sprain	Strain	Fracture	General Trauma	Neurotrauma
Laceration	Overuse	Other		

Perceived Severity of Injury: Mild Moderate Severe

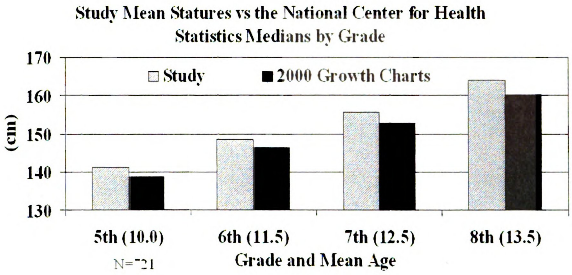
Summary of
Evaluation:____
____
____
____

Appendix G



Study Mean Statures vs the National Center for Health Statistics Medians by Grade
170
160
150
140
130
(cm)
Study
2000 Growth Charts
5th (10.0)
6th (11.5)
7th (12.5)
8th (13.5)
N=721
Grade and Mean Age

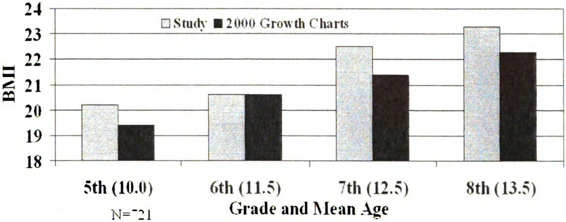
Appendix H



Study Mean Statures vs the National Center for Health Statistics Medians by Grade
Study
2000 Growth Charts
170
160
150
140
130
(cm)
5th (10.0)
6th (11.5)
7th (12.5)
8th (13.5)
N=721
Grade and Mean Age

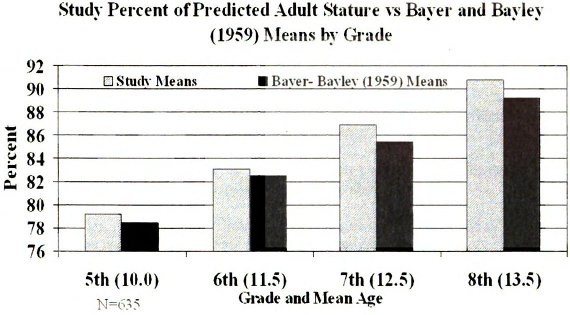
Appendix I

Study Body Mass Index Means vs National Center for Health Statistics 85th Percentile by Grade



N=721

Appendix J



Study Percent of Predicted Adult Stature vs Bayer and Bayley (1959) Means by Grade
Study Means
Bayer- Bayley (1959) Means
Percent
92
90
88
86
84
82
80
78
76
5th (10.0)
6th (11.5)
7th (12.5)
8th (13.5)
Grade and Mean Age
N=635

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