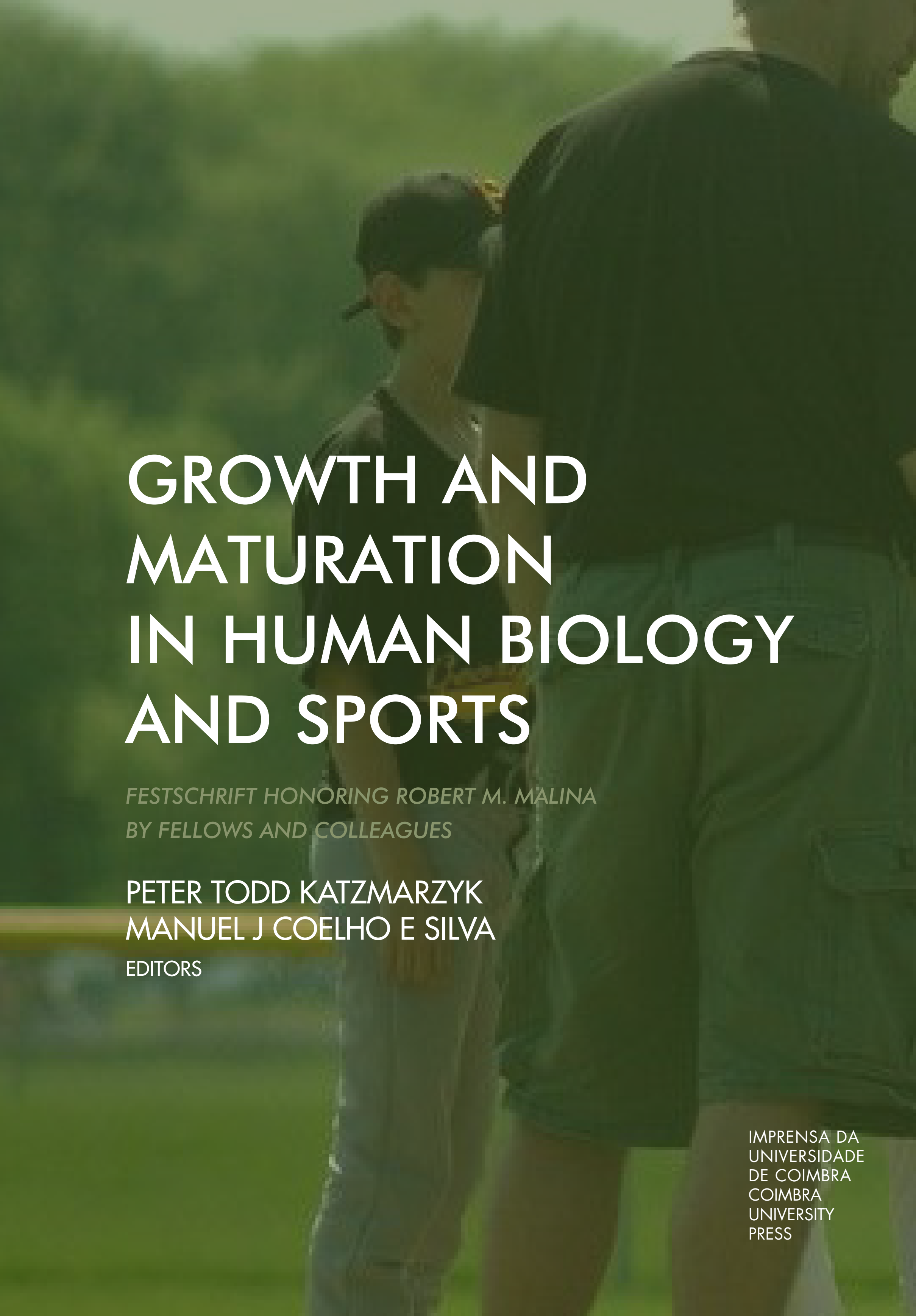

GROWTH AND MATURATION IN HUMAN BIOLOGY AND SPORTS

FESTSCHRIFT HONORING ROBERT M. MALINA BY FELLOWS AND COLLEAGUES

PETER TODD KATZMARZYK
MANUEL J COELHO E SILVA
EDITORS

IMPRENSA DA UNIVERSIDADE DE COIMBRA
COIMBRA UNIVERSITY PRESS

BIG LEAGUE DREAMS: A BRIEF LITERATURE REVIEW AND COMMENTARY ON THE YOUTH BASEBALL PLAYER

JC Eisenmann

Bob Malina, left side of priest, and his father and coach, Joe Malina, right side of priest.

INTRODUCTION

This paper provides an overview of the literature on the youth baseball player. I chose this topic for the Festschrift because aside from our interest in child growth, maturation and physical activity, Professor Malina and I share a passion for baseball and the study of the child and adolescent athlete. His interest in baseball stems from stickball and the New York City Police Athletic League; and mine from riding my bicycle with my baseball glove hanging from the handlebar looking for a neighborhood "pickup" game (on a related note, we have engaged in conversations of the lack of unstructured play among contemporary youth). We have both coached our sons' youth baseball teams. Interestingly, he is a New York Mets fan, while I am a Yankees fan. It is likely that Professor Malina's interest in the game of baseball influenced two of his first papers on throwing (Malina, 1968; 1969). Finally, it is perhaps fitting that I am writing this chapter in October – the month of the Major League Baseball playoffs and the World Series.

The author coaching Little League baseball, May 2005.

THE SCIENTIFIC AND MEDICAL LITERATURE ON YOUTH BASEBALL

A search of PUBMED (http://www.ncbi.nlm.nih.gov/pubmed) was conducted on October 5, 2011 and revealed 1882 papers using the term 'baseball'. Limiting the search to 0-18 year olds resulted in 684 papers; however, many of these papers focused on biomechanics and/or injuries, mainly associated with throwing (i.e., shoulder and elbow injuries, etc.). When the search term 'injury' was added, 404 papers were identified thus 59% of the papers on baseball in youth are related to injury. Since I am neither a biomechanist nor an expert in athletic injuries, I will only summarize some of this literature. Obviously, additional research is warranted on the aspects of the physical growth and maturation of the young baseball player. Additional sources were provided by searches of Google and GoogleScholar.

"THE NATIONAL PASTIME": PARTICIPATION RATES

Baseball has long been referred to as the national pastime in American culture. Therefore, it seems many youth (mainly boys but some girls) would participate in the sport. A few papers have indicated that baseball is a common physical activity preference of U.S. children and adolescents. For example, baseball was the fifth most common activity of 6-8th grade (11-14 year olds) boys in North Carolina behind football, basketball, bicycling, and running (Harrell et al., 2003).

Little League baseball is the most widely known youth baseball organization probably because the U.S. regional qualifying games and the entire Little League World Series are televised on ESPN and ABC. Little League is actually the world's largest organized youth sports program with nearly 180,000 teams across the world (www.

littleleague.org). In 2010, about two million youth played in the U.S. compared to about 2.5 million in 1996, an overall decline of 25%. Likewise, the National Sporting Goods Association also reports that the number of youth aged 7 to 17 playing baseball fell 24% from 2000 to 2009. The only growth in youth baseball participation occurred in those who play more than 50 times a year (i.e., sport specialization – see section below). At the high school level, there are about 15,786 programs in the U.S., a number that ranks third among boys' sports.

In general, youth sport is an important outlet for physical activity in children and adolescents (Wickel & Eisenmann, 2007). Few studies have documented the energy cost of playing baseball. Recently, Leek et al. (2011) documented accelerometer-determined physical activity during organized baseball practices in youth aged 7-14 years in San Diego County, California. The overall mean for moderate-to-vigorous physical activity was about 50 minutes (approximately 50% of practice time; mean practice time ranged from 35 to 217 minutes) with about 30% of participants meeting physical activity recommendations ($\geq$60 minutes of moderate-to-vigorous physical activity) via baseball practice. The authors concluded that "The health effects of youth sports could be improved by adopting policies that ensure participants obtain moderate-to-vigorous physical activity during practices". However, it is important to remember that youngsters need to develop skill and learn the game as well – not just partake in moderate-to-vigorous physical activity!

GROWTH AND MATURATION OF YOUTH BASEBALL PLAYERS

In general, there are limited data on the growth and maturation of youth baseball players compared to other sports (Malina, 1994). Two early studies first noted the size and maturity differences of talented young baseball players in the Little League World Series (Hale, 1956; Krogman, 1959). A more recent study corroborated these findings. French et al. (French, Spurgeon, & Nevett, 2007) compared body size of youth baseball players from a local league team and 1995 Dixie Youth World Series teams with U.S. growth charts. In both samples, pitchers, shortstops, and first basemen exhibited larger body size (greater standing height, sitting height, lower limb height, upper limb length) than children who played other positions. The height of local little league players was similar to the median of reference data at ages 7-9 years. The height and weight of skilled players in both samples approximated the 75th percentiles at ages 10-13 years. The results suggest that baseball players exhibit larger body size than the normal population at young ages, and that body size may be an important criterion used by coaches to select and assign young players to certain positions. As for the latter point, Carda and Looney (1994) showed differences in height, weight, lean body weight and somatoplots among Division I collegiate players. Pitchers were found to be taller than infielders and outfielders and displayed more endomorphy and less mesomorphy than the outfielders. Among the infielders, first basemen were taller than second basemen and third basemen while shortstops were found to be taller than second basemen. With respect to weight, first basemen and catchers were found to be heavier than second basemen. The second basemen had less lean body mass than all other infield groups.

Only one longitudinal study of young baseball players could be found (Nariyama, Hauspie, & Mino, 2001). This study included 126 Japanese junior baseball players in addition to 39 basketball, 83 soccer, and 53 volleyball players, and 36 non-athletes. On average, baseball players were 0.2-0.3 standard deviations above the population mean with the final height being about 2 cm greater in baseball players than non-athletes. In addition, the mean age at take off (9.8+1.1 yrs), age at peak height velocity (13.1±1.0 yrs) and peak height velocity (9.3±1.2 cm) did not differ between baseball players and controls.

RELATIVE AGE EFFECT

In the early 1980s the observation was made that there are skewed distributions of birth dates in elite hockey players (Barnsley, 1988). Among players in two Canadian elite junior hockey leagues, birthdates decreased in frequency from January (the cutoff date for age groupings in youth hockey) through December. Among professional National League Hockey players, about 40% were born in the first quarter of the year, 30% in the second, 20% in the third, and less than 10% were born in the final quarter. Further investigations in a variety of chronological age grouped team sports (i.e., soccer) have reported that elite young athletes were more likely born in the early months of the selection year, a phenomenon known as the *relative age effect*.

As for baseball, the magnitude of the effect among Major League Baseball players is less than that found among other sports like soccer and hockey (Thompson & Barnsley, 1991). However, when examining the data by month instead of quarter that a baby born in the U.S. in August has a 50-60 percent better chance of making the big leagues than a baby born in July. Among (all star) Little League players, there is also a small effect (Thompson, Barnsley, & Stebelsky, 1992).

Cote et al. (2006) have extended this concept to determine whether when (birthdate – i.e., relative age effect) and where (birthplace) an athlete is born influence their likelihood of playing professional baseball. A relative age effect was found, and there was a birthplace bias towards smaller cities with professional athletes being over-represented in cities of <500,000 and under-represented in cities of >500,000. The authors concluded that contextual factors associated with birthplace contribute more influentially than relative age and that these factors are essentially independent in their influences on expertise development.

FUNCTIONAL CAPACITIES AND MOTOR SKILLS IN BASEBALL: GENERAL CHARACTERISTICS AND TRAINABILITY

Baseball is a game that requires the fundamental motor skills of throwing, catching, hitting and running. In baseball vernacular, the "five-tool" player is a complete performer - one who excels at hitting for average, hitting for power, baserunning skills and speed, throwing ability, and fielding abilities (http://en.wikipedia.org/wiki/Five-tool_player). Obviously, success in baseball requires exceptional locomotor, projection (throwing and striking), and reception (catching) skills and muscular strength and explosive/sprint/agility abilities. However, at younger ages it is important that proficiency in these fundamental motor skills are developed so that youngsters can enjoy the game of baseball.

Few studies have specifically documented the functional capacities of youth baseball players. In fact, aside from training studies where strength, etc. were measured at baseline, I could not locate a single paper where the primary purpose was to document the functional capacities and motor abilities of young baseball players. Due to the paucity of data on functional capacities and motor skills in youth baseball players, this section provides a brief overview of the motor skill development of throwing, hitting, and running, and the trainability of these skills.

Throwing

Motor skill development and biomechanics. The description of the motor sequence of the overhand throw has deep historical roots dating to 1938 (Wild, 1938). In addition, sophisticated biomechanical (kinetic and kinematic) descriptions have also been published. In general, the mature (stage 4) movement pattern is described as an opposition of movement as a contralateral forward step is added to previous stages. Basically, the foot opposite of the throwing arm steps (strides) forward in the preparatory phase. The weight of the body is then transferred forward from the rear foot (throwing arm side) to the opposite foot (stride foot) as the hips, trunk and shoulders rotate to the glovehand side of the body. By about age 5-6 years 60% of boys are able to execute the mature throwing pattern (Branta & Haubenstricker, 1984).

Once the mature motor pattern emerges, there is plethora of literature on the biomechanics of throwing, mainly in adults. Much of this interest in overhand throwing mechanics is due to the common occurrence of injuries to the throwing arm (see section on injury below). A three-dimensional biomechanical analysis of pitching technique in 24 adolescents (Nissen et al., 2007) showed the following: Average excursion of motion was: pronation/supination 63 ± 15 degrees, wrist flexion/extension 44 ± 14 degrees, and ulnar/radial deviation 12 ± 4 degrees. Explosive forearm motion occurred between ball release and maximal glenohumeral internal rotation with a peak pronation velocity of 2051 ± 646 $degrees\cdot s^{-1}$. Internal glenohumeral rotation range of motion was 125 ± 13 degrees and mean peak internal glenohumeral rotation velocity was 3343 ± 453 $degrees\cdot s^{-1}$. Thorax and pelvic motion peak velocities and accelerations occurred before the peak elbow varus moment, which occurred at 59% of the pitch cycle. The peak shoulder, elbow, and wrist velocities and accelerations occurred after the peak elbow varus moment. The pelvis squared to the plate at $51\pm10\%$ pitch cycle and the thorax at $59\pm7\%$ of the pitch cycle with maximal glenohumeral external rotation at 65% of the pitch cycle and ball release at $78\pm3\%$ of the pitch cycle.


The author's 15-year old son (Kaleb) pitching, June 2011.

Training studies. To strengthen the throwing arm for either performance (i.e., throwing velocity) or injury prevention, coaches, trainers, and players (and sometimes parents) use several techniques ranging from general resistance training to tubing exercises to throwing programs with weighted baseballs over specified distances, etc. In the adult literature, training studies have been divided into 4 categories: a) specific resistance training with an overload of velocity, b) specific resistance training with an overload of force, c) specific resistance training with a combination of overload of force and velocity, and d) general resistance training according to the overload of force (Van Den Tillaar, 2004). To date, few training studies examining the influence of throwing programs on performance have been conducted in children or adolescents.

A common approach to improving throwing arm strength is "long-toss". This type of program involves throwing at specified distances. Axe et al (1996) developed an age-specific distance-based interval throwing program for Little League-aged athletes (9-12 years) based on a mathematical model from maximal distance and speed measurements. However, the effectiveness of the throwing program was not been evaluated. Only one study (Escamilla et al., 2010) examining the effects of a conditioning program on maximum throwing velocity in young players has been published despite several coaches and commercial facilities offering such programs. In this study, thirty-four 11-15 year old baseball players were randomly divided into control and training groups. The training group performed 3 sessions per week, 75 minutes per session for 4 weeks. The training program consisted of a sport-specific warm-up, resistance training with elastic tubing, a throwing program, and stretching. After the 4-week program, throwing velocity increased from 25.1±2.8 to 26.1±2.8 $m \cdot s^{-1}$ (56.2 to 58.4 mph) in the training group with no change in the control group (from 24.2±3.6 to 24.0±3.9 $m \cdot s^{-1}$; ≈54 mph) (Escamilla et al., 2010).

Hitting

Motor skill development and biomechanics. Between age 6-7 years 60% of boys are able to execute the mature pattern for striking (Branta & Haubenstricker, 1984). Three-dimensional kinematic and kinetic analysis of adults shows that the hitter starts the swing with a weight shift toward the rear foot and the generation of trunk coil. As the hitter strides forward, force applied by the front foot equal to 123% of body weight promotes segment acceleration around the axis of the trunk. The hip segment rotates to a maximum speed of 714 $degrees \cdot s^{-1}$ followed by a maximum shoulder segment velocity of 937 $degrees \cdot s^{-1}$. The product of this kinetic link is a maximum linear bat velocity of 31 $meters \cdot s^{-1}$ (69 miles per hour) (Welch, Banks, Cook, & Draovitch, 1995). However, there are differences between adult and youth hitters. Escamilla and colleagues (2009) showed a small number of temporal differences between youth and adult hitters, with adult hitters taking significantly greater time than youth hitters during the stride phase and during the swing. Compared with youth hitters, adult hitters a) had significantly greater lead knee flexion when the hands started to move forward; b) flexed the lead knee over a greater range of motion during the transition phase (31 degrees versus 13 degrees); c) extended the lead knee over a greater range of motion during the bat acceleration phase (59 degrees versus 32 degrees); d) maintained a more open pelvis position at lead foot off ground; and e) maintained a more open upper torso position when the hands started to move forward and a more closed upper torso position at bat-ball contact. Moreover, adult hitters had greater peak upper torso angular velocity (857 $degrees \cdot s^{-1}$ versus 717 $degrees \cdot s^{-1}$), peak left elbow extension angular velocity (752 $degrees \cdot s^{-1}$ versus 598 $degrees \cdot s^{-1}$), peak left knee extension angular velocity (386 $degrees \cdot s^{-1}$ versus 303 $degrees \cdot s^{-1}$), and bat linear velocity at bat-ball contact (30 $meters \cdot s^{-1}$ versus 25 $meters \cdot s^{-1}$). These adult-child differences, especially the angular velocities, are probably in part due to the differences in body size, neuromuscular strength, and neuromotor recruitment.

Training studies. Szymanski and colleagues (Szymanski et al., 2007a; 2006; Szymanski, Szymanski, Bradford, Schade, & Pascoe, 2007b; Szymanski, Szymanski, Molloy, & Pascoe, 2004) have conducted a series of studies investigating the influence of resistance training and additional supplemental resistance exercises, namely wrist/forearm exercises and rotational medicine ball exercises on muscular strength and bat velocity in high school baseball players. The training programs consist of 3 days per week of periodized full-body resistance exercises (squat, bench press, etc.) along with additional rotational and full-body medicine ball exercises or wrist and forearm exercises for 2 or 3 days per week over 12 weeks. Overall, these studies have shown: 1) a general, periodized resistance exercise program improves muscular strength and bat velocity, 2) a 12-week stepwise periodized training program can significantly increase wrist and forearm strength and linear bat velocity, and additional wrist and forearm training increases wrist and forearm strength beyond general resistance training but increased wrist and forearm strength did not contribute to further increases in linear bat velocity, and 3) rotational medicine ball training 2 or 3 days per week improves rotation strength beyond general resistance exercise and further enhances bat velocity.

Running (Sprinting ability and agility)

Motor skill development. By about 4 years of age 60% of boys are able to execute the mature running pattern (Branta & Haubenstricker, 1984). In general, running speed (40 yard dash time, etc.) improves sharply from 5 to 8 years of age and then continues to improve throughout childhood and adolescence. Depending on if the test involves a standing or running start, some of the improvement may be due to initial reaction time and acceleration. Changes in agility (i.e., shuttle run, etc.) show a similar pattern of change.

Training for speed/agility. Running speed and agility are key attributes to athletic performance in sports such as baseball. In contrast to the literature on training for endurance capacity, few studies have been conducted in youth examining the effects of training for running speed and/or agility and none have been specifically conducted in youth baseball players. To enhance running speed and agility, various approaches have been utilized including repeated sprints of varying distance, plyometrics, and/or resistance training. A comprehensive review of these training methods and studies is beyond the scope of this chapter. In general, these approaches are effective at producing small but significant changes in sprint speed and agility test results in adolescent athletes. Studies in prepubescent children are less extensive so conclusions cannot be drawn.

BASEBALL ACADEMIES AND EARLY SPECIALIZATION

"Baseball Academies" and private lessons. The previous section reviewed the limited published studies on training to improve specific functional capacities and skills required in baseball. Despite the paucity of evidence showing improvement in baseball-related capacities, there are several specialized commercial entities that train/coach young baseball players in terms of skill development and performance. For example, a Google search using 'baseball academy' yielded hundreds of such facilities across the U.S. (i.e., Mountain West Baseball Academy, All Star Baseball Academy, The Baseball Zone, etc.). It is common for these clinics to charge $40-100 per hour for individual hitting or pitching lessons ("personal coaches"). Likewise, many of these facilities or other strength and conditioning-type centers offer programs to improve baseball-specific functional capacities (hitting power, throwing velocity and speed) using various methods or gadgets that lack scientific scrutiny.

The Dominican Republic experience. It is perhaps important to mention here that "true" baseball academies (i.e., boarding schools) are common in the Dominican Republic. According to Major League Baseball, 234 players or 27.7% of the 846 players are foreign born, representing 14 countries and territories. The Dominican Republic leads all with 86 players (37% of foreign born). Currently, 28 of 30 Major League Baseball teams have an academy in the Dominican Republic (mlb.com).

Early specialization. To some extent the type of training described above lends to early specialization in sport. Much has been written about early sport specialization and the related intensive training typically associated with it (Brenner, 2007; Malina, 2010). The main concerns and risks of early specialization center around both physical (overuse injury, overtraining) and psycho-social (burnout, social isolation, overdependence) issues (Malina, 2010). Furthermore, Malina writes that "Commitment to a single sport at an early age immerses a youngster in a complex world regulated by adults, which is a setting that facilitates social, dietary, chemical, and commercial manipulation". And finally, "Early identification of "talent" is no guarantee of success in sport during childhood, let along during adolescence and adulthood."

INJURY RATES IN YOUTH BASEBALL

Although baseball is generally considered a safe activity, it is estimated that there are over 100,000 acute baseball injuries yearly among 5-14-year old U.S. youth (Yen & Metzl, 2000). Compared to youth baseball leagues, injury rates in high school-aged athletes are easier to track due to surveillance systems and coverage of high school events by certified athletic trainers/sports medicine staff. In a nationally representative sample of 100 U.S. high schools for the 2005-2006 and 2006-2007 school years (Collins & Comstock, 2008), there was an estimated 131,555 baseball-related injuries (injury rate of 1.26 injuries per 1000 athletic exposures). The most commonly injured body sites were the shoulder (17.6%), ankle (13.6%), head/face (12.3%), hand/finger (8.5%), and thigh/upper leg (8.2%). The most common injury diagnoses were ligament sprains (incomplete tears) (21.0%), muscle strains (incomplete tears) (20.1%), contusions (16.1%), and fractures (14.2%). Although the majority of injuries resulted in a time loss of <7 days, 9.7% resulted in medical disqualification for the season and 9.4% required surgery.

Ball impact particularly to the chest results in a small but steady number of fatalities each year, many of which are widely publicized events. This catastrophic injury is known as commotio cordis. More specifically, it results from a disruption of the heart rhythm following a blunt blow to the precordial region of the heart at a critical time during the cycle of a heartbeat which triggers ventricular fibrillation (Abrunzo, 1991). Of 182 cases of commotio cordis reported in the U.S. Commotio Cordis Registry, 85 (47%) occurred during practice or competition (Doerer, Haas, Estes, Link, & Maron, 2007).

THROWING ARM INJURIES AND THE DEVELOPMENT OF PITCH LIMITS

Injury to the throwing arm is a common acute and chronic injury in youth baseball. Two reports have indicated that nearly half of pitchers report pain during a season (Lyman, Fleisig, Andrews, & Osinski, 2002; Lyman et al., 2001) with the frequency of elbow pain (26%) and shoulder pain (32%) being similar (Lyman et al., 2001). More recently, it was found that the risk of a youth pitcher sustaining a serious throwing injury (elbow or shoulder surgery or retirement due to throwing injury) within 10 years is 5% (Fleisig et al., 2011). Injury to the throwing arm has long been a concern in youth baseball (Maller & Torg, 1972), but has more recently been systematically studied with consideration of pitch volume (i.e., innings or number of pitchers/count) and pitch type (i.e., curveballs). Little League baseball has been instrumental in supporting the development of pitch count regulations, and in doing so have relied on the expert advice of Dr. James Andrews, renowned orthopedic surgeon of rotator cuff injuries and Founder and Medical Director of the American Sports Medicine Institute. These studies have consisted of following young pitchers for 1, 2, 5, and 10 years (Lyman et al., 2001; 2002).

In terms of pitch volume, it is not uncommon for a talented young pitcher to be relied upon to pitch a few times per week (besides often playing other key positions – shortstop or catcher – during non-pitching play, and possibly playing on more than one team)(Fleisig et al., 2011). The number of innings pitched is a risk factor for shoulder injury in youth baseball pitchers. Players who pitched more than 100 innings in a year were 3.5 (95% confidence interval = 1.2 to 10.4) times more likely to be injured. However, the number of innings pitched as a measure of pitching volume has limitations since some pitchers may throw several pitches per inning (walking several batters, etc.) with lower innings pitched. Thus, pitch count (e.g., actual number of pitches thrown) is a more accurate way to measure throwing arm use. In a 1-year (single season) study (Lyman et al., 2002) of 476 baseball pitchers ages 9 to 14 years there was a significant association between the number of pitches thrown in a single game and during the season and the rate of elbow and/or shoulder pain. Specific risk factors for elbow and shoulder pain are shown in Table 1. Based on this study, Little League Baseball became the first national youth baseball organization to adopt the pitch count (in 2008), instead of the number of innings pitched, as a more accurate way to measure the use of the pitching arm. A recent study has shown that pitch count regulations reduce the risk of shoulder injury in Little League Baseball by 50 percent (Little League Baseball, 2010).

Table 1. Risk factors for elbow and shoulder pain in young baseball pitchers.

Risk factors for elbow pain	Risk factors for shoulder pain
• increased age	• decreased satisfaction
• increased weight	• arm fatigue during the game pitched
• decreased height	• throwing more than 75 pitches in a game
• lifting weights during the season	• throwing fewer than 300 pitches during the season
• playing baseball outside the league	
• decreased self-satisfaction	
• arm fatigue during the game pitched	
• throwing fewer than 300 or more than 600 pitches during the season	

There is also concern for increased throwing arm injury given that some young pitchers may pitch on more than one team, and concomitantly play catcher. Indeed, pitching in travel ball "elite" and "select" programs and pitching in "showcase" events were associated with an increased risk of elbow and shoulder injury for those who also pitched in Little League Baseball and high school (Little League Baseball, 2010). Another study reported a trend for increased arm injury among pitchers who also played catcher (Fleisig et al., 2011).

Besides pitching count, another concern regarding pitching among many involved with youth baseball is the breaking ball (i.e., curveball and variations). The curveball is a type of pitch that imparts forward spin to the ball causing it to 'break' across and/or downward as it approaches the plate. The curveball is considered a more advanced pitch than the fastball and has often been suggested to pose a risk of injury to the elbow and shoulder. Therefore, many youth coaches and parents suggest that a pitcher be 16 years old (skeletally mature) before throwing the curveball. However, there is limited information that has described how young pitchers are impacted by throwing curveballs. In the earlier study by Lyman et al (2002), breaking ball pitches were shown to increase throwing arm pain with the curveball associated with a 52% increased risk of shoulder pain and the slider with an 86% increased risk of elbow pain. However, two recent long-term (5 and 10-year) studies found that throwing breaking pitches at an early age was not an injury risk factor (Little League Baseball, 2010; Fleisig et al., 2011).

Despite the attention on both pitch count and pitch type, the strongest risk factor for injury is a previous history of injury. One study found that previous injury predisposes young athletes to over five times greater risk of incident elbow and shoulder injury (Little League Baseball, 2010).

FINAL THOUGHTS AND COMMENTS

Considering that Professor Malina spent his childhood in New York City, I found the following conclusion of a paper to be amusing - …the distribution of 25,000 wooden baseball bats to attendees (i.e., "Bat Day") at Yankee Stadium did not increase the incidence of bat-related trauma in the Bronx and northern Manhattan (Bernstein, Rennie, & Alagappan, 1994). And finally, Karvonen (1976) found an increased longevity among American baseball players. May you have a long and enjoyful life Professor Malina.

REFERENCES

Abrunzo, T.J., 1991, Commotio cordis. The single, most common cause of traumatic death in youth baseball. *American Journal of Diseases in Childhood*, *145*(11), pp. 1279–1282.

Axe, M.J., Snyder-Mackler, L., Konin, J.G., & Strube, M.J., 1996, Development of a distance-based interval throwing program for Little League-aged athletes. *American Journal of*

Sports Medicine, 24(5), pp. 594–602.
Barnsley, R, 1988, Birthdate and success in minor hockey: The key to the NHL.Canadian Journal of Behavioural Science 20(2), pp. 167-176.
Bernstein, S.L., Rennie, W.P.and Alagappan, K., 1994, Impact of Yankee Stadium Bat Day on blunt trauma in northern New York City. *Annals of Emergency Medicine*, 23(3), pp. 555–559.
Branta, C. and Haubenstricker, J., 1984, Age changes in motor skills during childhood and adolescence. *Exercise and Sport Science Reviews* 12(1), pp. 467-520
Brenner, J.S., American Academy of Pediatrics Council on Sports Medicine and Fitness., 2007, Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics*, 119(6), pp. 1242–1245.
Carda, R.D. and Looney, M.A., 1994, Differences in physical characteristics in collegiate baseball players. A descriptive position by position analysis. *Journal of Sports Medicine and Physical Fitness*, 34(4), pp. 370–376.
Collins, C.L. and Comstock, R.D. 2008, Epidemiological features of high school baseball injuries in the United States, 2005-2007. *Pediatrics*, 121(6), pp. 1181–1187.
Côté, J., Macdonald, D.J., Baker, J. and Abernethy, B., 2006, When "where" is more important than "when": birthplace and birthdate effects on the achievement of sporting expertise. *Journal of Sports Sciences*, 24(10), pp. 1065–1073.
Doerer, J.J., Haas, T.S., Estes, N.A.M., Link, M.S. and Maron, B.J., 2007, Evaluation of chest barriers for protection against sudden death due to commotio cordis. *American Journal of Cardiology*, 99(6), pp. 857–859.
Escamilla, R.F., Fleisig, G.S., DeRenne, C., Taylor, M.K., Moorman, C.T., Imamura, R., Barakatt, E., et al., 2009, A comparison of age level on baseball hitting kinematics. *Journal of Applied Biomechanics*, 25(3), pp. 210–218.
Escamilla, R.F., Fleisig, G.S., Yamashiro, K., Mikla, T., Dunning, R., Paulos, L. and Andrews, J.R., 2010, Effects of a 4-week youth baseball conditioning program on throwing velocity. *Journal of Strength and Conditioning Research*, 24(12), pp. 3247–3254.
Fleisig, G.S., Andrews, J.R., Cutter, G.R., Weber, A., Loftice, J., McMichael, C., Hassell, N., et al., 2011, Risk of serious injury for young baseball pitchers: a 10-year prospective study. *American Journal of Sports Medicine*, 39(2), pp. 253–257.
French, K.E., Spurgeon, J.H. and Nevett, M.E., 2007, Anthropometric characteristics of Columbia, South Carolina, youth baseball players and Dixie Youth World Series players. *Research Quarterly in Exercise and Sport*, *78*(3), pp. 179–188.
Hale, C., 1956, *Physiological maturity of Little League baseball players*. Research Quarterly.
Harrell, J.S., Pearce, P.F., Markland, E.T., Wilson, K., Bradley, C.B. and McMurray, R.G., 2003, Assessing physical activity in adolescents: common activities of children in 6th-8th grades. *Journal of the American Academy of Nurse Practitioners*, 15(4), pp. 170–178.
Karvonen, M.J., 1976, Sports and longevity. *Advances in Cardiology*, 18(0), pp. 243–248.
Krogman, W., 1959, *Maturation age of 55 boys in the Little League World Series*. Research Quarterly, 30, pp. 54-56
Leek, D., Carlson, J.A., Cain, K.L., Henrichon, S., Rosenberg, D., Patrick, K. and Sallis, J.F., 2011, Physical activity during youth sports practices. *Archives of Pediatrics and Adolescent Medicine*, 165(4), pp. 294–299.

Little League Baseball, 2010, *The Learning Curve: Little League Seeks to Address Concerns, Answer Questions about Curveballs and Overuse*.

Lyman, S., Fleisig, G.S., Andrews, J.R. and Osinski, E.D., 2002, Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *American Journal of Sports Medicine*, 30(4), pp. 463–468.

Lyman, S., Fleisig, G.S., Waterbor, J.W., Funkhouser, E.M., Pulley, L., Andrews, J.R., Osinski, E.D., et al., 2001, Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine & Science in Sports & Exercise*, 33(11), pp. 1803–1810.

Malina, R.M., 1968, Reliability of different methods of scoring throwing accuracy. *Research Quarterly*, 39, pp. 149–160.

Malina, R.M., 1969, Effects of varied information feedback practice conditions on throwing speed and accuracy. *Research Quarterly*, 40, pp. 134–145.

Malina, R.M., 1994, Physical growth and biological maturation of young athletes. *Exercise and Sport Science Reviews*, 22, pp. 339–443.

Malina, R.M., 2010, Early sport specialization: roots, effectiveness, risks. *Current Sports Medicine Reports*, 9(6), pp. 364–371.

Maller, H.M. and Torg, J.S., 1972, Opening of the season: little league baseball pro and con. *Pediatrics*, 50(2), p. 341.

Nariyama, K., Hauspie, R.C.and Mino, T., 2001, Longitudinal growth study of male Japanese junior high school athletes. *American Journal of Human Biology*, 13(3), pp. 356–364.

Nissen, C.W., Westwell, M., Ounpuu, S., Patel, M., Tate, J.P., Pierz, K., Burns, J. P., et al., 2007, Adolescent baseball pitching technique: a detailed three-dimensional biomechanical analysis. *Medicine & Science in Sports & Exercise*, 39(8), pp. 1347–1357.

Szymanski, D.J., McIntyre, J.S., Szymanski, J.M., Bradford, T.J., Schade, R. L., Madsen, N.H. and Pascoe, D.D., 2007a, Effect of torso rotational strength on angular hip, angular shoulder, and linear bat velocities of high school baseball players. *Journal of Strength and Conditioning Research*, 21(4), pp. 1117–1125.

Szymanski, D.J., McIntyre, J.S., Szymanski, J.M., Molloy, J.M., Madsen, N. H. and Pascoe, D.D., 2006, Effect of wrist and forearm training on linear bat-end, center of percussion, and hand velocities and on time to ball contact of high school baseball players. *Journal of Strength and Conditioning Research*, 20(1), pp. 231–240.

Szymanski, D.J., Szymanski, J.M., Bradford, T.J., Schade, R.L. and Pascoe, D.D., 2007b, Effect of twelve weeks of medicine ball training on high school baseball players. *Journal of Strength and Conditioning Research*, 21(3), pp. 894–901

Szymanski, D.J., Szymanski, J.M., Molloy, J.M. and Pascoe, D.D., 2004, Effect of 12 weeks of wrist and forearm training on high school baseball players. *Journal of Strength and Conditioning Research*, 18(3), pp. 432–440.

Thompson, A. and Barnsley, R., 1991, Born to play ball": the relative age effect and Major League Baseball. *Sociology of Sport Journal*, 8, pp. 146-151.

Thompson, A., Barnsley, R. and Stebelsky, G., 1992, Baseball performance and the relative age effect: Does Little League neutralize birth date selection bias. *Nine*, 1, pp. 19–30.

Van Den Tillaar, R., 2004, Effect of different training programs on the velocity of overarm throwing: a brief review. *Journal of Strength & Conditioning,* 18(2), pp. 388-396.

Welch, C.M., Banks, S.A., Cook, F.F. and Draovitch, P., 1995, Hitting a baseball: a biomechanical description *The Journal of Orthopaedic and Sports Physical Therapy*, 22(5), pp. 193–201.

Wickel, E.E. and Eisenmann, J.C., 2007, Contribution of youth sport to total daily physical activity among 6- to 12-yr-old boys. *Medicine & Science in Sports & Exercise*, 39(9), pp. 1493–1500.

Wild, S., 1938, The behavior of throwing and some observations concerning its course of development in children. *Research Quarterly*, 9, pp. 20–24.

Yen, K.L., & Metzl, J.D., 2000, Sports-specific concerns in the young athlete: baseball. *Pediatric Emergency Care*, 16(3), pp. 215–220.