BIOMECHANICS IN YOUTH SPORTS

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This paper addressed the many roles of biomechanics in youth sports, especially in injury prevention and instructional/coaching practices. An injury prevention model to study the mechanisms of injury is proposed for youth sports and its use in a variety of sports is identified. In addition, the translation of principles of biomechanics into coaching language and visual evaluation techniques are presented to demonstrate how the gap between the science and practice of biomechanics in youth sports can be bridged.

KEY WORDS: youth sports, injury prevention, visual evaluation, coaching, biomechanics

INTRODUCTION: Youth sports may be defined by the age of the athletes that participate in sport. Based on this approach, youth sports has been considered as the participation in sports by individuals approximately 18 years of age or younger. In the United States, the age generally corresponds with the age of students when they graduate from high school. To some, youth sports has a connotation that is associated with more of a recreational approach to athletic participation. However, the level of participation of youth in sport ranges from those who become occasionally involved in recreational activities to those who engage in heavy, year round training regimens.

Table 1 Estimated Percent of Youth Enrolled in Specific Categories of Youth Sports[a]

Category of Activity	Estimated Age Range (yrs.)	Percent of Eligible Enrollees[b]	Approximate Number of Participants
Agency Sponsored Sports (i.e., Little League Baseball, Pop Warner Football)	5-17	45	22,000,000
Club Sports (i.e., Pay for Services: Gymnastics, Ice Skating, Swimming)	5-17	5	2,368,700
Recreational Sports Programs (Everyone Plays – Sponsored by Recreational Departments)	5-17	30	14,512,200
Intramural Sports (Middle, Junior, Senior High Schools)	13-18	10	451,000
Interscholastic Sports (Middle, Junior, Senior High Schools)	13-18	12[c] 40[d]	5,776,820 5,776,820

[a]Total population of eligible participants in the 5-17 year age category (1995) was estimated to be 48,374,000 by the National Center for Educational Statistics, U.S. Department of Education, 1989.
[b]Totals do not equal 100 percent because of multiple-category participation by some athletes.
[c]Percent of total population aged 5-17 years.
[d]Percent of high school-aged population (N = 14,510,000).

How many youth participate in sports by age and level of competition? This is a difficult question to answer because it varies by country and by the structural organization of youth sports within various countries, and because there is a paucity of good data to answer this question. It has been estimated that 20 million children in the United States between the ages of 6 and 16 years are involved in sports that are organized and supervised by adults (Seefeldt, 1987). This implies that the participant count is even larger if non-organized youth sports participants were added to the total. A recent paper (Ewing, Seefeldt, & Brown, 1999), commissioned by the Carnegie Corporation, documented the participation for specific categories of youth sports in the United States (Table 1).

The number of participants in sport, from youth to adulthood, can be represented by a pyramidal model (Figure 1). The greatest number of participants is evident at the youngest ages. The size of the population, for each age group, is represented by the area of the respective region of the pyramid. The slopes of the sides of the pyramid represent the drop out rate. It is likely that, in many countries, there is a rapid decline in sport participation from seven to 18 years of age and that this decline continues throughout adulthood.

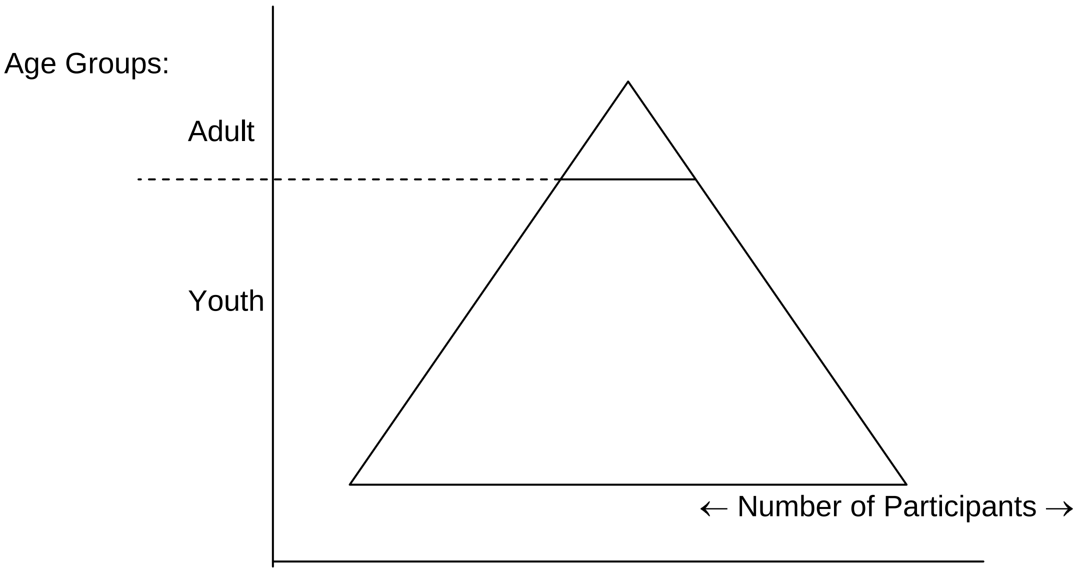


Figure 1 – Schematic representation of the age and number of participants in sport.

What role does biomechanics have to play in youth sports? The answer to this question is "The same as it has in adult sports." Generally, biomechanics can contribute to sport in several ways: injury prevention, performance enhancement, equipment design, rule modifications, and instructional/coaching practices. Since the role of biomechanics is the same, irrespective of the age of the sport participant, one might be led to conclude that there would be more biomechanics activity associated with youth sports because of the disproportionate number of participants involved in this age group in comparison to adult athletes. This is not the case. In fact, a review of the published reports from three years (1995-97) of the Journal of Applied Biomechanics and the 1999 Proceedings of the International Society of Biomechanics in Sports (Table 2) reveals proportionally few biomechanics studies of youth sports. The total number of studies and subjects (identified as under 18 years of age) reported were six and 70, respectively; whereas, 388 subjects 18 years and older were reported to have participated in 33 studies.

Table 2 Number of Biomechanics Studies and Subjects by Sport and Age Group

Sport	Age Group[a]				Age Group[b]			
	Youth (<18 yrs.)	Adult (≥18 yrs.)	Youth and Adult	No Specific Age Infor-mation	Youth (<18 yrs.)	Adult (≥18 yrs.)	Youth and Adult	No Specific Age Infor-mation
Alpine skiing		2:8						
Baseball					1:20	1:4		
Basketball								2:14
Crew								2:88
Cross country skiing		1:20						
Cycling		3:52		1:34				
Dance	1:2	2:14						
Diving			1:20					
Fencing							1:12	1:4
Figure skating			1:16					1:24
Football		1:12						
Football and baseball			1:52					
Golf		1:4						
Gymnastics	1:15	1:3		2:93				
Gymnastics and diving		1:6						
Karate								1:12
Kayak						1:10		
Marshall arts								1:66
Rifle shooting								1:1
Rock climbing				1:6				
Roller skating					1:6			
Roller skiing			1:8					
Sailing								1:2
Ski jumping				1:20				
Softball						1:8	1:10	
Swimming			1:797	2:813		2:36		3:17
Tennis				2:23			1:8	5:85
Track and field	1:19	6:112	2:45	5:65		3:46		2:13
Trampolining	1:8	1:3				1:1		
Triathlon		1:11						
Volleyball						1:8		1:1
Water polo		2:26						
Weightlifting		1:4		2:32				
Sum	4:44	23:275	7:938	15:1086	2:26	10:113	3:30	21:327

[a]Data from the Journal of Applied Biomechanics (1995-97).
[b]Data from the 1999 Proceedings of the ISBS.
[c]Data in table is reported as number of studies:total number of subjects.

What is behind this system of focusing the greatest effort in research and application on the smallest population of sports participants? The answer is organization, prestige, and money. Even though there are highly organized groups within various sports, much of youth sports tends to be recreational. Often, it is not until highly skilled youth athletes begin to emerge that coaches, the news media, and researchers begin to focus attention on them. With the exception of a few sports (e.g., women's gymnastics, figure skating, and swimming), where youth participants are also the top level competitors, proportionally little attention is given to research and application of biomechanics to youth sports. The professional sport model is driven by money. This money is often raised at the bottom of the pyramid of participants, through registration fees and the purchase of tickets for sporting events and sport paraphernalia, and is spent on the top levels of performers (e.g., prospective participants and participants of Olympic and professional sports). In general there is a void in the study of youth sport participants. Therefore, an opportunity exists for biomechanists to make widespread contributions at this level, especially when taking into consideration the greater number of youth sport participants and the relative longevity of sport participation of young athletes in comparison to adult athletes. The remainder of this paper will focus on two of the roles of biomechanics in youth sports – injury prevention and instructional/coaching practices.

INJURY PREVENTION: The epidemiology of sports injuries involves the study of the distribution and etiology (causes) of injuries for the purposes of reducing the severity and incidence of sports injuries in the future (Caine, Caine, & Lindner, 1996). In general, there is a direct relationship between the age of athletes and level of their sport competition, and the incidence and severity of injury. Thus, on a per person basis, youth sports participants tend to have fewer and less severe injuries than their highly competitive and older counterparts. This may be a partial explanation for the tendency of youth sports to have fewer, if any, and less skilled medical personnel available at their practices and competitions to address their immediate injury needs.

Study of the etiology of sports injuries in youth is more difficult than in adult and highly skilled competitors because young athletes tend to be supervised less and the availability of trained medical personnel and other researchers to record the exact nature and mechanism of injury is often not available. There is a tendency for the study of injuries in young athletes to be retrospective, relying on the recall of children and their parents to elucidate the cause, type, and severity of injury. Under this approach, data that is collected is general (e.g., knee injury). On the other hand, more prospective studies take place in adult sports, providing better understanding of specific injuries (e.g., anterior cruciate injury of the knee) and their injury mechanisms.

By studying the mechanisms of injury in youth sports, the incidence and severity of injuries may be able to be reduced through rational decisions and recommendations regarding the a) modification of sports rules; b) design and use of sports equipment and personal protective supplies, devices, and clothing; c) equation of competition; and d) establishment of age requirements. The mechanisms of injury are the processes by which injuries occur in sport. These processes involve complex interactions among many factors associated with the performer (internal factors) and sport environment (external factors). Each athlete comes to the sport setting with his/her own set of physical, psychological, and cognitive characteristics. These characteristics are internal to the performer and are the result of past experiences and development. Therefore, they change over time. Examples of these characteristics are as follows: a) physical characteristics – strength, somatotype, weight, gender, skeletal maturation; b) psychological characteristics – trait anxiety, self-confidence, risk taking, state anxiety; and c) cognitive characteristics – knowledge of rules, knowledge of safe performance, knowledge about the opponent, knowledge about how to use training equipment, strategy. Each specific characteristic may have an influence on an athlete's potential for injury. In studying injuries associated with youth involvement in sport, it is important to consider specific personal characteristics. Even though there are many specific characteristics associated with each athlete, coaches and biomechanists may have insight into the physical, psychological, and cognitive characteristics of athletes and thus be able to identify a few key characteristics to study as logically important contributors to injury.

Each sport setting, whether for training or actual sport competition, contains many environmental factors that can be contributors to injury. However, they can also change with time. These environmental factors are external to the athlete. They include items such as condition of the field, characteristics of implements used in sport, properties of protective equipment, and forces and torque's applied to the athlete. Similar to the specific characteristics of the performer, there are many specific characteristics associated with each sport environment. Insight into determining which of these are important factors in contributing to injury in sport requires the insight of coaches and biomechanists to selectively identify specific environmental factors to study.

An injury mechanism model (Brown, 1987) has been previously developed and modified (Brown & Learman, 1998) to include concepts related to the study of the biomechanics of injury in youth sports (Figure 2). Elements in this model include (a) a questionnaire to collect data on the athlete (performer) and the sport environment; (b) prospective research on injury mechanisms and the mechanics of performance to help understand the injury process; and (c) recommendations to prevent injuries and reduce their severity. The schematic model presented in Figure 2 suggests that injuries in sport result from interactions, on an individual level, between the athlete and the sport environment. The suggested relationship between performer and environment is in accord with Lysens et al. (1984) who stated that "sports injuries result from a complex interaction of identifiable risk factors at a given point in time."

A two stage process was developed to study the biomechanics of injury in youth sport athletes. The first stage involved the development of a questionnaire to collect retrospective information about the performer, sport environment, and interaction between the performer and sport environment. In general questionnaire items address the physical characteristics of young athletes, history of their sport participation, level and incidence of pain associated with their training and participation in sport, conditions under which their sport was conducted, and sites and types of injuries sustained. Questionnaire items must be specifically developed for each sport and rely upon the insight of knowledgeable coaches and sport biomechanists. A questionnaire was initially developed to specifically address injury mechanisms in teenage powerlifting (Brown & Kimball, 1983; Brown & Abani, 1985). This questionnaire has been modified to make it compatible with the specific terminology and sport involvement characteristics of other youth sport groups and its utility has been tested on these groups (Brown & McKeag, 1987; Brown et al, 1996).

The second stage of this process involved drawing relationships between regions of the body with relatively high levels and incidences of pain (areas susceptible to overuse and acute injury), injury sites and types, and the kinetics of selected sport skills that were suspected of precipitating these problems. In powerlifting, for example, from the questionnaire administered to teenage subjects, it was learned that they experienced a relatively high level and incidence of pain in the low back region and that fifty percent of their reported injuries occurred in this region (Brown & Kimball, 1983). Based on the questionnaire results, a kinetic model was developed to subsequently study the movement patterns in powerlifting (Brown & Abani, 1985) in order to more fully understand the injury mechanisms.

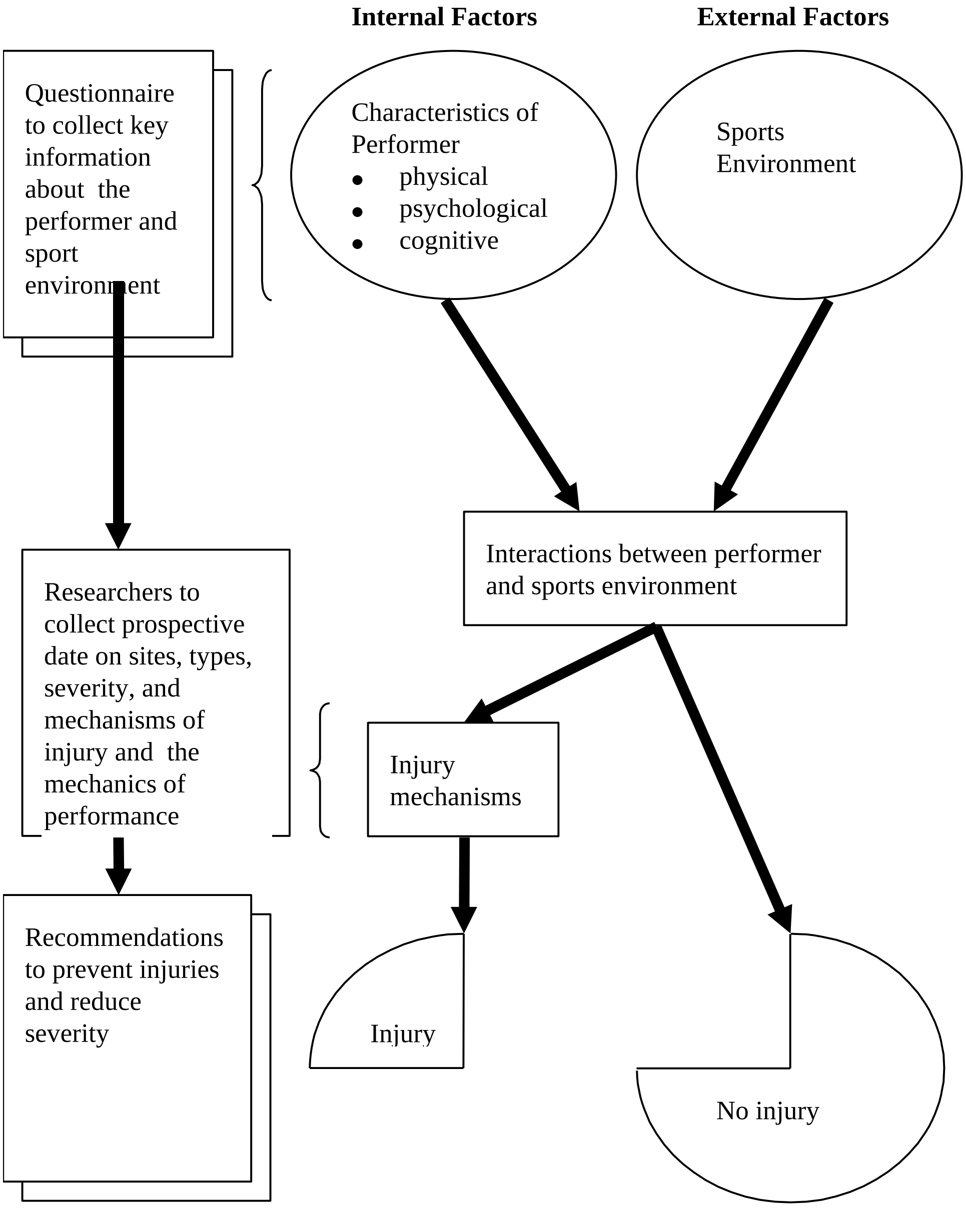


Figure 2 – Schematic model for the study of injury mechanisms in youth sports.

This process was successfully employed in collecting data on youth participants in powerlifting, pairs skating, gymnastics, and rowing. It has resulted in a strategy that can be used to collect similar information on other youth sport groups. It should be noted that this process is not as definitive in sports classified as "open" (sports in which the physical activities are somewhat unpredictable – e.g., soccer, American football, and basketball) in comparison to those that are classified as "closed" (e.g., shot put, weightlifting, and crew).

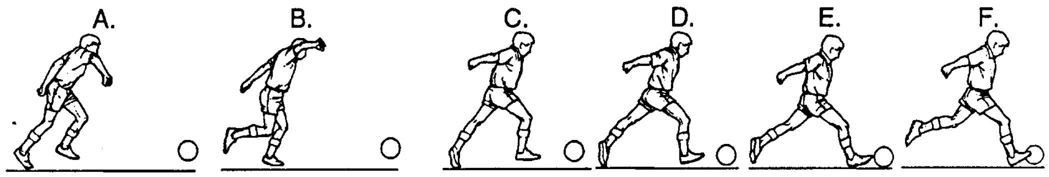
INSTRUCTIONAL/COACHING PRACTICES: In addition to injury prevention, another role of biomechanics in youth sports is relates to instructional and coaching practices.

Translating Principles of Biomechanics into Coaching Language

Many youth sport coaches are volunteers who become involved because of their enjoyment of and/or past participation in a particular sport. Others become involved as coaches because they want to share in the sport experience with their child who has signed up to play. Irrespective of the reasons why adults become involved, many lack formal coaching education, and they can not be expected to contribute many hours beyond the time they train their team and guide their athletes in competition.

How can biomechanics be helpful to youth sports coaches when most coaches are not readily receptive to instruction on the center of gravity of the human body, moments of inertia of body segments, conservation of linear and angular momentum, and the like? To reach them with these and other concepts, that may assist them to develop a better understanding of the performance of sport skills, there must be a translation of these principles of biomechanics into more practical concepts (bridging the gap between the science and practice of biomechanics). This type of translation should a) use words that are more common to coaches, even if they may lack a precise physics definition, and b) include visual support for understanding movement patterns (sequential drawings, video, CD, etc.). An example of this translation is drawn from an instructional manual in the sport of soccer (Brown & Williamson, 1992), specifically the skill of kicking. The approach, pre-impact, impact, and follow-through are four elements of the kick that are described. Focusing on the pre-impact phase, there are many translated statements and visual associations made (Table 3).

Table 3 Soccer Example of the Translation of Biomechanics into Coaching Language

Components of Kicking	Excerpted Verbal Description for Coaches	Principles of Biomechanics
Approach	"A full-speed run to the ball is not usually desirable because a player will not likely be able to control the kick that follows."	• Speed versus accuracy
	"For maximum ball velocity, the hip of the kicking leg should be fully extended before swinging the leg forward."	• Stretch reflex • Elastic property of muscle • Application of force over a longer period of time
		
Pre-Impact	"As the player contacts the ground, the support leg acts like a strut: to block the forward movement of its hip, to start the forward rotation of the other hip, and to initiate forward swing of the thigh of the kicking leg."	• Eccentric force causes rotation
	"Just before impact, the speed of the thigh's forward rotation should rapidly decrease. This is associated with a rapid extension of the knee of the kicking leg."	•Kinetic link principle • Conservation of angular momentum

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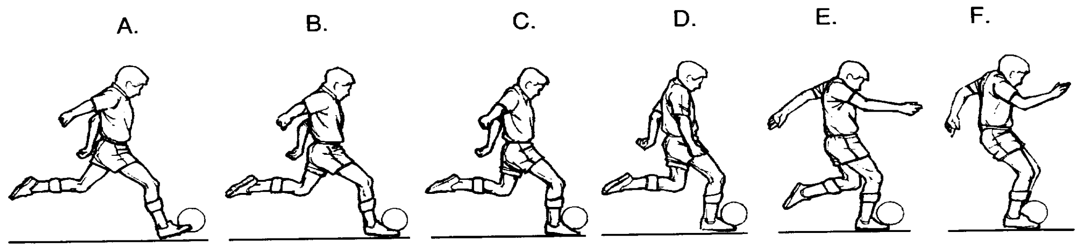
<tr><td colspan="3">
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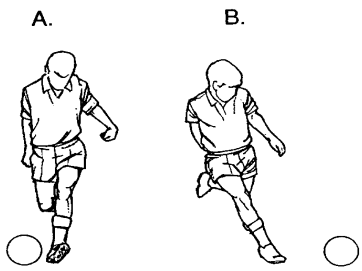
<tr><td>Angled Versus Straight Approach – Hip Rotation</td><td>“In the angled approach to the ball (B), because of the increased range to swing the hip of the kicking leg forward from the opened position, greater forward velocity can be achieved in the kicking leg.”</td><td>• Application of force (torque) over a longer period of time</td></tr>
<tr><td colspan="3">
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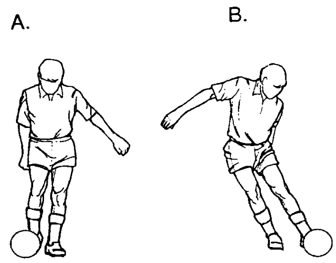
<tr><td>Angled Versus Straight Approach – Lever Length</td><td>“In the angled approach (B), the trunk leans away from the ball, allowing the player to fully extend the kicking leg. The longer lever achieved in the angled approach provides for potentially greater ball velocity in the kick.”</td><td>• Influence of longer lever</td></tr>
<tr><td colspan="3">
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Teaching Youth Sports Coaches to Visually Evaluate Performance

Coaches of young athletes may know the skills they want to teach their athletes, but are often limited in their ability to observe their athletes’ performances of skills and to subsequently provide suggestions as to how to correct performance errors and/or enhance performance. In addition, they may dedicate much of their time and effort in their coaching to organizational and administrative responsibilities. There are two general approaches that coaches employ to evaluate sport skills. The first, and least productive, is a product evaluation. It focuses on the results of performance. Telling an athlete, who finishes last in a 50 meter sprint to swim faster is stating the obvious. The important question involves the process of how to swim faster. Coaches need to learn ways to observe the performances of skills by their athletes in order to provide feedback on the form or process of performance.

Therefore, an important ability that should be taught to coaches is visual evaluation techniques (Brown, 1982)). These techniques involve the establishment of an observation strategy and use of simplified principles of biomechanics. Table 4 provides a listing of visual evaluation techniques and a brief explanation of each.

Table 4 Visual Evaluation Techniques for Coaches

VISUAL EVALUATION CATEGORIES AND TECHNIQUES	EXPLANATIONS/COMMENTS
Vantage Point Techniques	The relative position of the coach and athlete determine what will be seen.
1. Select the proper observational distance.	Observe from afar to get an overall understanding and then move in closer to look at the specifics.
2. Observe the performance from different angles.	Each angle may provide additional information about performance.
3. Observe the performance from a carefully selected angle.	This is especially important when the coach may get only a few chances to observe.
4. Observe activities in a setting that is not distracting.	Observing an athlete in isolation may assist the coach in focusing on an individual performer.
5. Observe the performance in a setting with a vertical and /or horizontal reference line.	When the orientation of body parts are important, these references may be helpful.
6. Observe a skilled reference model.	This technique may provide insight, but should be used cautiously when athletes differ in size, strength, and maturation.
Movement Simplification	Initial observations should attempt to simplify the movement. An understanding of performance in a simplified form will be helpful in subsequent observations.
7. Observe slower moving body parts.	The extremities and striking implements often move very fast. To gain initial understanding of the sport skill, coaches should focus on the slower moving body parts (usually the hip area).
8. Observe separate components of a complicated skill.	This involves breaking down a complex skill into component parts (e.g., preparatory phase, movement phase, and follow-through).
9. Observe the timing of performance components.	In order for a sport skill to be performed correctly, there is an appropriate sequencing that should be followed.
Balance and Stability	Simplified concepts of balance, stability, center of gravity, and base of support are introduced to assist the coach in understanding their relationships to stability and mobility.
10. Look at the supporting parts of the body.	This technique helps the coach focus on the base of support.
11. Look at the height of the body and body parts.	The concept of the center of gravity in balance and stability is introduced indirectly.
Movement Relationships	The motion of one or more body parts may influence the motion of other parts. These relationships may cause either desired or undesired performance of skills.
12. Look for unnecessary movement.	A waste of physical effort will be very costly in repetitive movements (e.g., running, swimming, or cycling) over the course of prolonged activity.
13. Look for movement opposition.	Structurally, the movements of the legs and arms are often used to counterbalance one another.
14. Observe the motion and direction of swinging body parts.	Sports skills (e.g., jumping activities) involve the transfer of momentum of the parts to the momentum of the whole.
15. Look at the motion of the head.	Anatomically, the motion of the head and neck through their connection with the spine provide insight into movement of the entire body.
16. Observe the location and	This observation technique is a simplification of the

direction of applied forces.	concepts of the effects of eccentric forces, forces through the center of mass, and force couples.
Range of Movement	Range of movement can be used to influence control and/or force and velocity.
17. Observe the range of movement of body parts.	The range of movement may influence the force and/or speed that the athlete attains in the sport skill.
18. Look for the stretching of muscles.	The concepts of stretch reflex and storage of elastic energy are important when attempting to achieve maximum force and/or velocity.
19. Look for a continuous flow of motion.	In most skills, smooth transition from one phase of movement to the next is essential.

Schematically, Figure 3 highlights the observational strategy that accompanies these visual evaluation techniques. The coach is encouraged to use vantage point techniques whenever analyzing sport techniques. During the initial observations, the movement simplification techniques should be employed to develop a general understanding of how the athlete performs the skill. Based on what is learned from the movement simplification techniques, the coach can concentrate on the specific observable problems and the nature of the skill (e.g., balance, projectile, maximum force and/or velocity, accuracy) to focus subsequent observation. These visual evaluation techniques have been taught to beginning and advanced coaches. At minimum, they provide an understanding that coaching should not be limited to organization and administration of their athletes.

Visual Evaluation Techniques		Application
Vantage Point	←	Always consider Vantage Point Techniques.
Movement Simplification	←	Consider during initial observations.
Balance and Stability Movement Relationships Range of Movement	} ←	Use of these techniques is based on what is learned through movement simplification and the specific elements of the sport skill.

Figure 3 - Schematic approach to the use of the visual evaluation techniques.

CONCLUSION: Even though youth sport participants far outnumber adult participants in sport, there is a paucity of biomechanics studies and application at the youth sport level. By bridging the gap between the science and practice of biomechanics, opportunities exist for biomechanists to make widespread contributions to youth sports in many ways: injury prevention, performance enhancement, equipment design, rule modifications, and instructional/coaching practices.

REFERENCES:

Brown, E.W. (1982). Visual evaluation techniques for skill analysis. *Journal of Physical Education, Recreation & Dance,* **53**(1), 21-26, 29.

Brown, E.W. (1987). Mechanisms of injury in young athletes. In E. W. Brown & C. Branta (Eds.), *Competitive sports for children and youth - An overview of research and issues* (pp. 107-113). Champaign, IL: Human Kinetics Publishers.

Brown, E.W., & Abani, K. (1985). Kinematics and kinetics of the dead lift in adolescent power lifters. *Medicine and Science in Sports and Exercise*, **17**(5) 554-563.

Brown, E.W., & Kimball, R.G. (1983). Medical history associated with adolescent powerlifting. *Pediatrics*, **72**(5), 636-644.

Brown, E.W., & Learman, J. (1998). Process for effectively studying the biomechanics of injury in youth sports. In H. J. Riehle & M. M. Vieten (Eds.), *Proceedings II of the XVI international symposium on biomechanics in sports* (pp. 304-307). Konstanz, Germany: UVK- Universitatsverlag Konstanz.

Brown, E.W., & McKeag, D.B. (1987). Training, experience, and medical history of pairs skaters. *The Physician and Sportsmedicine*, **15**(4), 100-114.

Brown, E.W., & Williamson, G. (1992). Kicking. In E. W. Brown (Ed.), *Youth soccer- A complete handbook* (pp. 209-242). Carmel, IN: Cooper Publishing Group.

Brown, E.W., Witten, W.A., Espinoza, D.M., Witten, C.X., Wilson, D.J., Wisner, D.M., Weise, M., & Learman, J. (1996). Attenuation of ground reaction forces in dismounts from the balance beam. In T. Bauer (Ed.), *Proceedings of the XIII international symposium of the International Society of Biomechanics in Sports* (pp. 114-117). Thunder Bay, Ontario, Canada: Lakehead University Press.

Caine, C., Caine, D, & Lindner, K. (1996). The epidemiologic approach to sports injuries. In D Caine, C. Caine, & K. Lindner (Eds.), *Epidemiology of sports injuries* (pp. 1-13). Champaign, IL: Human Kinetics.

Ewing, M., Seefeldt, V., & Brown, T. (1999*). Role of orgnaized sports in the education and health of American children and youth*. New York, NY: Carnigie Corporation.

Lysens, R., Steverlynck, A., Auweele, Y., Lefevre, J., Renson, L., Claessens, A., & Ostyn, M. (1984). The predictability of sports injuries. *Sports Medicine*, **1**(1), 6-10.

Seefeldt, V. (1987). Benefits of competitive sports for children and youth. In V. Seefeldt (Ed.), *Handbook for youth sports coaches* (pp. 3-15). Reston, VA: American Alliance for Health, Physical Education, Recreation, and Dance.