Physiological and sport skill characteristics of Olympic developmental soccer athletes
by Miriam Lydia Vanderford

A thesis submitted in partial fulfillment of the requirements for the degree Of Master of Science in Health and Human Development
Montana State University

Abstract:
Although many studies have examined the physiological profile of soccer athletes, no comprehensive studies have been conducted on developmental soccer athletes in the United States. Therefore, the purpose of this study was to quantify physiological and sport-specific skill characteristics of Olympic Developmental soccer athletes by age group and region. Following written informed consent, 59 male athletes (age=14.6±2 yrs; wt=60.5±1.4 kg; ht=172.4±1.2 cm) completed a battery of tests to determine oxygen consumption (VO2max), heart rate (HRmax), ventilation (VEmax)1 respiratory exchange ratio (Rmax)1 anaerobic threshold (AT), and blood pressure (BPrestzmax) during a Bruce graded exercise test (GXT). Anaerobic power [peak power (PR), mean power (MP)1 total work output (TWO)] was achieved using a Wingate test. Leg power (vertical squat and countermovement jumps), percent body fat, and flexibilities (trunk, spine, hip, knee, and ankle) were assessed. Agility and sport-specific skill were determined using accepted sport-specific protocols (T-test, line drill test, juggling test, Johnson wall volley, and modified-Zelenka circuit). Factor analyses with subsequent MANOVAs indicated significant ($p<.05$) main effects across age only. When compared to values reported for athletes of similar age and activity, these athletes were similar in aerobic power and anaerobic power/capacity, lower in leg power, and similar in agility and flexibility. Overall, this study has shown that although these athletes were similar in aerobic performance, improvements in anaerobic power, agility, and sport skill should be addressed. It is hoped that these results may serve as a point of reference for high school and club soccer coaches, as well as for further studies conducted with athletes of this age group and sport.

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Miriam Lydia Vanderford

A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

Miriam Lydia Vanderford

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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This work is first of all dedicated to God who has been my ever constant source of strength and guidance (Proverbs 3: 5-6 - "Trust in the Lord with all your heart and lean not to your own understanding. In all your ways acknowledge him, and he will direct your paths.") I would also like to dedicate this work to my family who has always stood behind me to encourage and support me in every dream I pursued.

VITA

The author of this work is Miriam Lydia Vanderford. She was born on July 31, 1972, in Rome, Georgia, to Rev. Kenneth A. and Mrs. Louise G. Vanderford. Lydia received her Bachelor of Science degree June, 1994, from the Valdosta State University Education Department with an emphasis in Athletic Training. This work was written in partial fulfillment of her Master of Science degree from the Montana State University Department of Health and Human Development, where her major field of study is Exercise Physiology. Her professional experience includes a graduate teaching assistantship at Montana State University, where her duties included working as a certified athletic trainer for the MSU Athletic Department. Lydia was also a Chief Athletic Trainer for the 1996 Centennial Olympics.

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ABSTRACT

Although many studies have examined the physiological profile of soccer athletes, no comprehensive studies have been conducted on developmental soccer athletes in the United States. Therefore, the purpose of this study was to quantify physiological and sport-specific skill characteristics of Olympic Developmental soccer athletes by age group and region. Following written informed consent, 59 male athletes (age=14.6±2 yrs; wt=60.5±1.4 kg; ht=172.4±1.2 cm) completed a battery of tests to determine oxygen consumption (VO_{2max}), heart rate (HR_{max}), ventilation (VE_{max}), respiratory exchange ratio (R_{max}), anaerobic threshold (AT), and blood pressure ($BP_{rest/max}$) during a Bruce graded exercise test (GXT). Anaerobic power [peak power (PP), mean power (MP), total work output (TWO)] was achieved using a Wingate test. Leg power (vertical squat and countermovement jumps), percent body fat, and flexibilities (trunk, spine, hip, knee, and ankle) were assessed. Agility and sport-specific skill were determined using accepted sport-specific protocols (T-test, line drill test, juggling test, Johnson wall volley, and modified-Zelenka circuit). Factor analyses with subsequent MANOVAs indicated significant ($p<.05$) main effects across age only. When compared to values reported for athletes of similar age and activity, these athletes were similar in aerobic power and anaerobic power/capacity, lower in leg power, and similar in agility and flexibility. Overall, this study has shown that although these athletes were similar in aerobic performance, improvements in anaerobic power, agility, and sport skill should be addressed. It is hoped that these results may serve as a point of reference for high school and club soccer coaches, as well as for further studies conducted with athletes of this age group and sport.

CHAPTER 1

INTRODUCTION

Soccer is an intermittent activity sport, taxing both the aerobic and anaerobic systems (Raven, Gettman, Pollock, & Cooper, 1976; Withers, Roberts, & Davies, 1977). During competition, a player's workload intensity will range from walking to sprinting (Reilly & Thomas, 1976). In order to sufficiently sustain the ability to perform during a soccer match, a player must possess a strong anaerobic component that combines strength, speed, and power (Berg, LaVoie, & Latin, 1985; Kirkendall, 1985). Flexibility and agility are also key factors that allow for the quick stops, starts, and turns these athletes must perform (Tumilty, 1993), as well as sport-specific skills that are essential to successfully compete at a national and international level (Marey, Boleach, Mayhew, & McDole, 1991; Raven et al., 1976).

Numerous studies have investigated various physiological characteristics of adult soccer players during actual competition or following training (Ekblom, 1986; Leatt, Shephard, & Plyley, 1987; Mosher, Rhodes, Wenger, & Filsinger, 1985; Raven et al., 1976; Reilly & Thomas, 1976; Rhodes, Mosher, McKenzie, Franks, Potts, & Wenger, 1986). Of the several studies published on youth soccer (Caru, Le Coultre, Aghemo, & Limas, 1970; Chin, So, Yuan, Li, & Wong, 1994; Garganta, Maria, & Pinto, 1992; Garganta, Maria, Silva, & Natal, 1992; Jones & Helms, 1992; Leatt et al., 1987; Mosher et al., 1985; Tumilty & Smith, 1992), only two have examined U.S. athletes, utilizing limited standard laboratory procedures and information on characteristics specific to soccer athletes (Berg et al., 1985; Kirkendall, 1985). At this time, little attention has been directed towards agility and sport-specific skill assessment in young soccer athletes, especially addressing age and regional differences at the developmental level of competition (Leatt et al., 1987; Mosher et al., 1985).

During the last 10 years, the popularity of youth soccer in the United States has greatly increased (Berg et al., 1985; Kirkendall, 1985). According to the 1993-94 Athletics Participation Survey conducted by the National Federation of State High School Associations, boys' soccer ranks as one of the top five most popular high school sports with the number of participants reaching 255,538. Soccer also ranks as one of the top ten most popular high school sports (National Federation of State High School Associations, 1995). Therefore, it seems there is a disparity between the popularity of soccer in this country, and attempts to study the physiological and performance characteristics of these young athletes are warranted.

Purpose

The purposes of this study were to quantify physiological and sport-specific skills of Olympic Developmental Program soccer athletes and to examine whether differences existed between age group or region. Results were also compared to other intermittent sport competitors.

Significance of the Study

The results of this comprehensive study should be of value to soccer athletes, coaches, and sport scientists as they attempt to more clearly define optimal levels of physiological fitness and sport skills specific to youth soccer. This should ultimately lead to more effective conditioning and training regimens.

Research Objectives

This investigation attempted to fulfill the following objectives:

1. Quantify physiological response of youth soccer athletes.
2. Quantify sport-specific skills of youth soccer athletes.

Null Hypotheses

For the purposes of this study, the following null hypotheses were tested:

1. There will be no significant difference observed in the physiological responses of ODP soccer athletes when classified by age group and region.
2. There will be no significant difference observed in the quality of sport skill of ODP soccer athletes when classified by age group and region.

Assumptions

Assumptions regarding this investigation were:

1. Subjects were adequately informed by investigators on all procedures and phases of the study to ensure optimal understanding of physiological and sport skill testing.
2. Subjects were expected to exert maximal effort for optimal physiological and sport skill responses.

Limitations

Limitations regarding this investigation were:

1. Due to the small sample size involved in the study, any inference to a larger population would be difficult.
2. Due to a narrow age range, inference to other age populations would be limited.

3. Due to travel across long distances and time zones, the limited opportunity for athletes to fully acclimatize would have compromised optimal testing response.
4. Due to meals being provided by the ODP soccer camp, control of nutritional intake was limited throughout the week.
5. Due to the subjects' varying camp schedules and coaching requirements, consistent testing schedules were improbable.

Delimitations

Delimitations regarding this investigation included:

1. Soccer athletes were selected from the Olympic Developmental Program, which should have elicited a high degree of athletic performance and maximal response.
2. Prior to participating in the study, athletes were exposed to all testing procedures to enhance familiarity and optimal response potential.
3. Aerobic assessments were conducted no earlier than 48 hours following arrival in Bozeman for those traveling from lower altitudes to become acclimatized.
4. Subjects were instructed to consume meals high in carbohydrates for restoration and maintenance of muscle glycogen throughout the week.
5. Time between testing periods and sport competition were kept in a consistent manner to minimize an undesired effect on test response.
6. Circadian rhythmicity was addressed by testing individuals of the same group at different times throughout the day so that the subjects' shifts in chronobiological rhythm would balance out.

Definition of Terms

Aerobic capacity -	The amount of aerobic energy the body is able to produce independent of time, using aerobic glycolysis and beta oxidation. This variable is measured as the amount of oxygen uptake (VO_2) an individual is capable of consuming during exercise (Fox, Bowers, & Foss, 1989; Rhodes et al., 1986).
Aerobic energy -	The breakdown of glycogen and fat in the presence of oxygen through aerobic glycolysis and beta-oxidation, respectively, followed by passage of fuel substrates into the Krebs cycle and electron transport system (ETS) for the production of ATP (Fox et al., 1989).
Aerobic power -	The rate at which one can maximally consume oxygen, defined as VO_{2max}, which is obtained from an athlete during exercise (Fox et al., 1989; Rhodes et al., 1986).
Agility -	The ability to change direction quickly while maintaining body control (Semenick, 1990b).
Anaerobic capacity -	The total amount of work one is able to perform in the absence of adequate oxygen, using immediately available ATP and phosphagen derived from anaerobic glycolysis and phosphagen systems (Fox et al., 1989; Tharp, Johnson, & Thorland, 1984).
Anaerobic energy -	The ATP produced by the breakdown of glycogen and/or phosphocreatine in the absence of oxygen (Fox et al., 1991).
Anaerobic power -	The highest amount of work performed in a specified period of time; usually during the first or second 5-second period of time (Tharp et al., 1984).
Flexibility -	The range of motion (ROM) about any given joint, measured by goniometric technique (American Academy of Orthopaedic Surgeons, 1965).
Muscular (leg) power -	The rate of work performed by the lower extremity musculature, as measured by vertical jump (Fox et al., 1989; Semenick, 1990c).
Residual volume -	The amount of gas left in the lungs following a maximal expiration (Fox et al., 1989).

CHAPTER 2

REVIEW OF LITERATURE

Although several studies have been conducted on international soccer players (Bangsbo, Norregaard, & Thorso, 1991; Davis et al., 1992; Ekblom, 1986; Ghosh, Ahuja, & Khana, 1987; Oberg, Ekstrand, Moller, & Gillquist, 1984; Reilly & Thomas, 1976; Thomas & Reilly, 1979), a limited number have focused on athletes in the United States (Berg et al., 1985; Kirkendall, 1985; Raven et al., 1976). More importantly, no comprehensive physiological and sport-specific skill studies have been published. The majority of studies have quantified the competitive season's effect on physiological response, have documented physiological differences between laboratory and field testing, have provided partial athletic profiles with limited sport application, or have quantified the efficacy of various training regimens (Bangsbo & Lindquist, 1992; Davis et al., 1992; Ghosh et al., 1987; Malomsoki, Ekes, Martos, & Nemeskeri, 1990; Reilly & Thomas, 1977; White, Emery, Kane, Groves, & Risman, 1988).

Anthropometric Status

Sport performance is affected by the ratio of body fat to lean body mass (LBM) (Riendeau, Welch, Crisp, Crowley, Griffin, & Brockett, 1958). An increase in LBM enhances speed and agility, whereas an increase in body fat negatively influences quickness of horizontal movements (Maud & Shultz, 1984; Raven et al., 1976; Riendeau et al., 1958). Thus, body composition is an important determinant in assessing the physical capabilities of soccer athletes (Green, 1992; Leatt et al., 1987).

Percent body fat values reported for soccer athletes are similar to those of other intermittent activity athletes. Professional soccer athletes exhibited percent body fat ranging from 7.3% to 13.3% (Chin et al., 1992; Davis et al., 1992; Raven, et al., 1976; Rhodes et al., 1986). These values are similar to those reported for other intermittent activity athletes involved in baseball, rugby, field hockey, and judo (Hagerman, Starr, & Murray, 1989; Maud & Shultz, 1984; Reilly & Borrie, 1992; Thomas, Cox, LeGal, Verde, & Smith, 1989).

There are a number of anthropometric techniques that are used to assess body composition. These include hydrostatic weighing, skinfold measurements, electrical bioimpedence, and air displacement (Boulier, Fricker, Thomasset, & Apfelbaum, 1990; Davis et al., 1992; Dempster & Itchiness, 1995; Hagerman et al., 1989; Leatt et al., 1987; Maud & Shultz, 1984; McCrory, Gomez, Bernauer, & Mole, 1995; Jackson & Pollock, 1977; Rhodes et al., 1986). Hydrostatic weighing is considered the gold standard in the clinical setting when attempting to quantify body composition in both general and athletic populations (American College of Sports Medicine, 1991; Horswill, Lohman, Slaughter, Boileau, & Wilmore, 1990; Meyers et al., 1992; Williford, Smith, Mansfield, Conerly, & Bishop, 1986). Subject habituation, however, is essential for optimal success. Reported test-retest reliability coefficients for hydrostatic weighing have ranged from .93 to .99 (Katch, Michael, & Horvath, 1967).

Skinfold measurement is a simple technique to perform. The technique is noninvasive, requires limited subject participation/experience, and does not require expensive laboratory equipment. Thus, it is often used in settings where limited funding is available. In addition, skinfold measurements are also used to compare accuracy of measurements obtained by other anthropometric methods (American College of Sports Medicine, 1991). Skinfold correlation coefficients have ranged from .78 to .90, slightly lower than values established for hydrostatic weighing (Stout, Housh, Johnson, Housh, Evans, & Eckerson, 1995).

Aerobic Power

In the sport of soccer, an adequately trained aerobic system is necessary to sustain long-term performance during a match, and provides a foundation for sport-specific training of other energy systems (Korshunov & Kirillov, 1979). Studies documenting the distance and intensity of work required of athletes during soccer competition have indicated that players travel an average of 10 km during a match, with distances ranging from 8.68 to 10.98 km (Bangsbo & Lindquist, 1992; Bangsbo et al., 1991; Reilly & Thomas, 1979; Tumilty, 1993). Additional research has quantified work load by both distance, and by the percentage of time spent at various intensities of exercise, i.e., rest, low-intensity running, high-intensity running. Bangsbo and colleagues (1991) reported that standing accounted for 17.1% of the time spent during a competitive match, with walking, low-intensity running, and high-intensity running accounting for 40.4%, 35.1%, and 8.1%, respectively. Other studies have revealed that high intensity running accounts for 19% of time played or approximately 2.1 km (Bangsbo & Lindquist, 1992; Withers, Maricic, Wasilewski, & Kelly, 1982).

Some researchers, however, have expressed a concern for additional aerobic training. Bangsbo et al. (1991) reported a 5% decrease in distance from the first to second halves of a soccer match, a factor possibly influenced by a change in the amount of low-intensity running. This decrease in distance traveled from the first to the second half, may reflect insufficient aerobic training. Other studies have also indicated a decrease in game distance or intensity, as indicated by heart rate (HR) telemetry, from the first to the second half of play, attributing the change to possible physical fatigue (Ali & Farrally, 1991; Reilly & Thomas, 1976).

Assessments of heart rate (HR) and maximal oxygen uptake (VO_{2max}) during exercise are commonly performed to quantify an individual's functional capacity (Bangsbo et al., 1991; Davis et al., 1992; Raven et al., 1976; Rhodes et al., 1986). Heart rate measurements are obtained to identify the level of intensity and is the single most used indicator of aerobic fitness (American College of Sports Medicine, 1991). Of these techniques, however, VO_{2max} is considered to be the criterion by which other measurements in the clinical setting are compared (McArdle, Katch, & Katch, 1991).

Investigators examining soccer athletes have used both HR and VO_{2max} to quantify aerobic power (Bangsbo et al., 1991; Raven et al., 1976). Various HR values recorded for soccer athletes include supine HR_{rest} values of 54-65 bpm, HR_{mean} during play of 170 bpm, and HR_{max} values ranging from 188 to 195 bpm (Ali & Farrally, 1991; Raven et al., 1976; Rhodes et al., 1986; Thomas & Reilly, 1979).

Interestingly, VO_{2max} values obtained from professional and young elite soccer players are similar. Aerobic power of professional soccer athletes have ranged from 53.7 $ml \cdot kg^{-1} \cdot min^{-1}$ to 66.4 $ml \cdot kg^{-1} \cdot min^{-1}$, depending on the position played (Bangsbo et al., 1991; Chin, Lo, Li, & So, 1992; Raven et al., 1976; Rhodes et al., 1986; Tumilty, 1993). Midfielders seem to possess the highest aerobic power when compared to other field positions, possibly related to their dual role as both attackers and defenders during a match (Davis et al., 1992). Studies involving young athletes have reported VO_{2max} values of 50 $ml \cdot kg^{-1} \cdot min^{-1}$ in club players between the ages of 11-12 (Berg et al., 1985), 42.3-50.2 $ml \cdot kg^{-1} \cdot min^{-1}$ in non-elite soccer players ages 14-18 (Caru et al., 1970), and 57.7 and 59 $ml \cdot kg^{-1} \cdot min^{-1}$ in elite under-18 (U-18) and under-16 (U-16) athletes, respectively (Leatt et al., 1987).

The method typically used to assess VO_{2max} in both athletic and general populations is a symptom-limited graded exercise test (GXT) using standardized treadmill protocols (Bangsbo, Michalsik, & Petersen, 1993; Berg et al., 1985; Binkhorst, Saris, Noordeloos, van't Hof, & de Haan, 1986; Thomas & Reilly, 1979). The Bruce protocol is widely used to assess cardiovascular response of individuals ranging in age from 4 through adulthood (Binkhorst et al., 1986; Bruce, Kusumi, & Hosmer, 1973; Cumming, Everatt, & Hastman, 1978; Cumming & Hnatiuk, 1980; Cyran, Grzeszczak, Haas, & Baylen, 1993). Reliability and validity coefficients for the Bruce protocol have been firmly established across a wide array of populations (Bruce et al., 1973).

Anaerobic Power/Capacity

Along with aerobic conditioning, anaerobic capacity/power are also critical components for successful soccer performance. Soccer players have been documented sprinting 15 meters every 90 seconds, and performing some level of high intensity work once every 30 seconds (Reilly & Thomas, 1976). Other studies have indicated that soccer involves high intensity, intermittent work loads requiring both anaerobic capacity and power (Bowers & Fox, 1988; Maud & Shultz, 1984; Reilly & Borrie, 1992).

Several methods have been employed to evaluate the anaerobic capacity of athletes involved in sports such as baseball (Hagerman et al., 1989), rodeo (Meyers, Wilkinson, Elledge, Tolson, Sterling, & Coast, 1992), and soccer (Davis et al., 1992; Rhodes et al., 1986). These methods include blood analysis quantifying lactate concentration, indirect calorimetry to determine anaerobic threshold (as a percent of VO_{2max}), and ergometry tests that measure peak/mean power, and total work output (Bangsbo et al., 1993; Bangsbo et al., 1991; Chin et al., 1992; Malomsoki et al., 1990; Rhodes et al., 1986). Studies have documented mean lactate values of 4.4 $mmol \cdot l^{-1}$

following competitive matches, 7.8 $mmol \cdot l^{-1}$ after interval field tests, and peak lactate values of 12.9 $mmol \cdot l^{-1}$ following exhaustive treadmill running in professional soccer athletes (Bangsbo & Lindquist, 1992; Bangsbo et al., 1993; Bangsbo et al., 1991). Other studies have revealed anaerobic threshold values ranging from 80.5% to 88% of VO_{2max} (Bunc, Heller, Leso, Sprynarova, & Zdanowicz, 1987; Chin et al., 1992; Leatt et al., 1987; Rhodes et al., 1986). Another study using the Wingate cycle ergometer test revealed peak power outputs of 14.6 to 14.79 $W \cdot kg^{-1}$, a mean power output of 9.72 $W \cdot kg^{-1}$, and a mean fatigue index of 38.3% across all positions (Davis et al., 1992).

For noninvasive research, the Wingate test is the most utilized method for quantifying intermediate-term anaerobic performance (Bouchard, Taylor, Simoneau, & Dulac, 1991; Maud & Shultz, 1989). Peak power, mean power, total work output, and a decline in work performance (referred to as fatigue index) are obtained as a subject attempts to pedal on a leg or arm ergometer for 30 seconds with maximal exertion (Bar-Or, 1987). The Wingate is recommended for use in both athletic and general populations ranging in age from 8 through adulthood (Blimkie, Roche, & Bar-Or, 1986; Davis et al., 1992; Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980; Hagerman et al., 1989; Inbar & Bar-Or, 1986; Tharp et al., 1984). Test-retest reliability and validity have been firmly established (Bouchard et al., 1991).

Muscular (Leg) Power

Muscular strength, power, and endurance are also critical components for successful performance during soccer competition. The quick accelerations and changes of direction required of soccer athletes demand immediate and consistent muscular response (Rhodes et al., 1986).

Several techniques have been employed for the assessment of muscular response. These include vertical jump, isokinetic dynamometry, cable tensiometry, and the 1-repetition maximum technique (Clarke, Bailey, & Shay, 1952; Glencross, 1966; Holmes & Alderink, 1984; McArdle et al., 1991; Williford, Kirkpatrick, Scharff-Olson, Blessing, & Wang, 1994). Of these procedures, the vertical jump test is a reliable and frequently used indicator of leg power for both laboratory and field settings (Berg et al., 1985; McArdle et al., 1991; Oberg et al., 1984; Tumilty, 1993). The vertical jump protocol provides immediate feedback to assess explosive muscular power in a sport-specific, weight-bearing manner, typically experienced in competition (Faina, Gallozzi, Lupo, Colli, Sassi, & Marini, 1988).

The vertical jump test was developed in 1921 by D. A. Sargent (Gray, Start, & Glencross, 1962), and is primarily used to quantify explosive response of the hip, knee, and ankle (Kraemer & Newton, 1994). Although a correlation between jump height and power may be made if the length of jump time or a nomogram are used, the majority of soccer studies have not reported this information. Vertical jump values reported for junior to professional soccer athletes have ranged from heights of 41 to 66 cm, limiting extrapolation to actual power (Ekblom, 1986; Green, 1992; Islegen & Akgun, 1988; Kirkendall, 1985; Raven et al., 1976; Reilly & Thomas, 1977; White et al., 1988). In studies examining more than one division or team, however, the more elite teams jumped higher (Kirkendall, 1985; Reilly & Thomas, 1977), indicating that the vertical jump test could be used to differentiate between higher-skilled and lower-skilled athletes.

Fortunately, findings from studies performed on athletes of other sports using the vertical jump test have reported their results in units of power. Values have ranged from 14.3 to 18.0 $W \cdot kg^{-1}$ in adolescent track athletes (Hollings & Robson, 1991), and high school football placekickers (Meyers, Marley, Duhon, Ingram, & Sterling, 1995). Power outputs have also been established for national judo, rugby, tennis, and hockey players, as well as cyclists, sprinters, and endurance runners (Maud & Shultz, 1984; Thomas et al., 1989; Vandewalle, Peres, Heller, Panel, & Monod, 1987).

The opportunity to correlate the vertical jump with anaerobic cycle ergometry enhances the opportunity to evaluate anaerobic response with accuracy using multiple sport-specific criteria. With the addition of a force plate or center-of-gravity device with specific equations or standardized nomograms, power can be calculated in lieu of expensive laboratory equipment, i.e., isokinetic dynamometry, with reasonable accuracy.

The Harman (Harman, 1991) and Lewis nomograms (Fox et al., 1989) are two such examples of standardized equations used in conjunction with a vertical jump test. The Lewis formula is an older and more widely known formula commonly used by educators, coaches, and researchers. The Harman nomogram is a more recently developed formula that was developed to adjust for the incorrect estimates observed with the Lewis nomogram. The Lewis formula supposedly represents the power exerted on the body by gravity on its return to the ground, rather than the power produced by the leg muscles in generating force to initiate the jump (Harman, Rosenstein, Frykman, Rosenstein, & Kraemer, 1991). Correlations of the two formulas to values established using a force-platform, however, have shown little difference. Correlation coefficients comparing the Lewis nomogram to peak and average power produced on a force-platform were .83 and .72, respectively, while use of the Harman nomogram resulted in coefficients of .88 and .73, respectively (Harman et al., 1991).

Agility and Sport Skill

The ability to accelerate, to control directional change, and to maintain ball control are mandatory skills an athlete must possess in order to successfully play soccer. Research conducted on soccer athletes indicates that during a match, players change speed and direction approximately every five seconds (Kirkendall, 1985). Leatt and colleagues (1987) suggested that the demands for sport-specific skill, teamwork, anticipation of an opponent's movements, and agility during a match may be more important than the physiological variables frequently examined in an exercise science laboratory. Leatt's speculation is supported by data from other researchers which indicate that for successful performance in intermittent-activity sports (i.e., basketball, lacrosse, tennis, and volleyball), an athlete must possess agility, as well as the skills specific to that sport (Beise & Peaseley, 1937; dos Remedios, 1993; Gates & Sheffield, 1940; Ghosh et al., 1987; Marey et al., 1991; Plisk & Stenersen, 1992). Studies quantifying the field sense of soccer athletes, however, are limited, making it difficult to determine the accuracy of Leatt's supposition (Raven et al., 1976; White et al., 1988).

Two types of testing programs have been used to evaluate agility and sport skill: 1) agility tests, which require an athlete to perform movements *similar* to those required during competition, and 2) specific skill tests in which an athlete performs the *actual* skills used during competition. Examples of agility tests that closely imitate movements in soccer include the T-test and the line drill test. These tests measure controlled directional change and the capacity to anaerobically perform at maximal levels of play (Semenick, 1990a; Semenick, 1990b). These tests have been employed in other sports training programs such as basketball and lacrosse (dos Remedios, 1993; Plisk & Stenersen, 1992). Due to the recent development of these tests, however, test-retest reliabilities have not been established.

Skills that are highly desirable and fundamental to soccer include ball control, kicking accuracy, and the ability to maneuver oneself around and between opposing players. One technique used to assess ball control is the juggling test, which requires a soccer player to tap a soccer ball in the air as many times as possible within a 30-second period of time (Baumgartner & Jackson, 1987). During the test, any part of the body may be used to keep the ball in the air, with the exception of the arms and hands. This technique has been accepted by the American Professional Soccer League as a viable test of soccer skill in young athletes (Baumgartner & Jackson, 1987).

Kicking accuracy is typically assessed utilizing some form of target (i.e., wall or board) representing the dimensions of a soccer goal. The Johnson wall volley test requires a player to kick a ball from a 15-foot restraining line into a goal-sized target on a wall and then trap the ball on the rebound as many times as possible within a 30-second time period. Validity and reliability coefficients of .85 and .92, respectively, have been established for this test (Collins & Hodges, 1978).

To account for overall soccer ability, the modified-Zelenka test or circuit, has proven to be an excellent test of skill and is purported to imitate the cardiorespiratory demands of a soccer match (Nettleton & Briggs, 1980). Test scores have correlated significantly with coaches' perception of an athlete's field ability, while observed heart rates are similar to those found during a soccer match (Nettleton & Briggs, 1980). The correlation reported between the Zelenka circuit time and the subjective assessment of match performance was reported to be .81 ($p<.01$) (Nettleton & Briggs, 1980) which may indicate the circuit's potential to differentiate between higher and lower skilled athletes.

Flexibility

Flexibility, or joint range of motion (ROM), is vital for prevention of injury and improvement of sport performance (Ekstrand & Gillquist, 1982). Flexibility has become an integral part of the physical profiles of athletes in such sports as baseball (Hagerman et al., 1989), and soccer (Berg et al., 1985; Chin et al., 1992; Ekstrand & Gillquist, 1982; Leatt et al., 1987; Raven et al., 1976).

The results of flexibility studies on soccer athletes are equivocal, with reports indicating either less flexibility than the general population, (Chin et al., 1992; Ekstrand & Gillquist, 1982, 1983; Oberg et al., 1984; Rhodes et al., 1986), or greater ROM than values exhibited by individuals within the same age group (Berg et al., 1985; Leatt et al., 1987; Raven et al., 1976). Studies in which athletes have exhibited limited flexibility have primarily involved adult soccer players, while those in which more flexibility was observed examined mostly young athletes. Thus, ROM differences may be influenced by the age of athletes examined. Since muscular inflexibility has been shown to create a predisposition for injury (Ekstrand & Gillquist, 1983), assessment of flexibility may be critical for minimizing injury potential in young athletes.

Goniometry is an accepted method used for the measurement of joint ROM (American Academy of Orthopaedic Surgeons, 1965; Hubley-Kovey, 1991). Since soccer is a sport which predominately involves the lower extremities, measurements of flexibility generally include the ankle, knee, and hip (Agre & Baxter, 1987; Oberg et al., 1984). Reliability studies have revealed goniometric error to be mainly attributed to intratester variation (Ekstrand, Wiktorsson, Oberg, & Gillquist, 1982; Hellebrandt, Duvall, & Moore, 1949; Low, 1976; Salter, 1955); however, by paying attention to certain specifications (i.e., hard surface for the subject to lie on, stabilization of other joints during movement, and accurate marking of reference points), intratester interassay coefficients of variance (variation for the same tester during different measuring sessions) of 1.9 ± 0.7% have been confirmed (Ekstrand et al., 1982).

Summary

In summary, soccer is a sport which encompasses many physiological and sport skill characteristics. Few comprehensive studies have been conducted concerning these attributes. Examined together, these physiological and sport-specific skill factors should provide a more complete understanding of an elite developmental soccer player's capabilities.

Young ODP athletes were selected for this study because of the limited amount of published research concerning youth soccer in the United States. Of the two studies conducted with youth soccer athletes in the United States, limited comprehensive information was provided concerning physiological response and sport-specific skills. In addition, no research has been published addressing characteristics of soccer athletes at the Olympic developmental level of competition.

For the purposes of testing, the youth selected for the study were divided by age group and region. With regard to region, it was hypothesized that exposure to a greater number of games played per season would improve a soccer athlete's physiological status and sport-specific skills. With the number of games played per season ranging from 30 to 100 over a 13 state region, a disparity of experience and skill level might be apparent.

A couple of factors responsible for the disparity of seasonal games played between regions are the natural environment and the availability of competitors. For example, in states such as Montana and Alaska, the weather limits outdoor competition to approximately 4 or 5 months per year. In addition, the sparse population of these states limits the number of accessible teams within reasonable driving distance. Thus, both the environment and the number of teams available for competition may limit the athletes' playing time, and ultimately, their physical skill development.

The harsher environment in the northern tier of states also influences the number of practices possible, often forcing coaches and athletes to devise alternative forms of training. In states such as California, however, year-round competition and an ample number of soccer athletes exist, providing an unlimited number of games and/or practices and potentiating greater opportunity for skill development. To test this hypothesis, players from the 11 Western and 2 Non-continental states were divided into subregions based on the number of games played per season. Data were also grouped by age to determine maturational effects on physical response.

CHAPTER 3

METHODOLOGY

This study was conducted with athletes participating in the Olympic Development Program camps from 11 Western and 2 Non-continental states comprising Region 4 of the U. S. Youth Soccer organization. The camp participants were divided into 3 groups by their year of birth: 81 or U-14 athletes (12-14 years old), 80 or U-15 athletes (14-15 years old), 79 or U-16 athletes (15-16 years old). For purposes of this study, the ODP athletes were also divided into three subregions depending on the number of games they played per season, ranging from 75-100 for Subregion A, 55-65 games for Subregion B, and 30-45 games in Subregion C. Subregion A (n=18) consisted of Southern California, Northern California, Western Washington, Nevada, Idaho, and Utah. Subregion B (n=20) consisted of Colorado, Arizona, Eastern Washington, New Mexico, Wyoming, Oregon, and Hawaii. Subregion C (n=21) consisted of Alaska and Montana. Subjects were selected from volunteers who had responded to a letter of invitation mailed to each of the 604 participating athletes prior to the start of camp.

Following written informed consent from each subject and his parent/guardian, and clearance from the Montana State University Human Subjects Committee, physiological and sport-specific skill assessments were performed on 59 Olympic Development Program (ODP) soccer athletes. A partial assessment (graded exercise test) was performed on one subject who elected to not complete the full test battery. The values for this subject were included in the study due to the significance of the aerobic data. Following random selection from the soccer players at ODP camp who volunteered for the study, the subjects accompanied the primary investigator to the Human Performance and Ergonomics Laboratory to become acquainted with testing procedures.

Tests were arranged so as to allow the subjects sufficient rest, considering both the intensity of exercise testing and the primary energy system used (Fox et al., 1989). The order of testing for the study was as follows: Wingate anaerobic test, flexibility measurements, vertical jump test, and maximal graded exercise test (GXT). Hydrostatic weighing, skinfold procedures, and the agility/sport-specific field tests were conducted at predetermined times based on the availability and scheduling of the facilities required to successfully complete the tests.

The time of day in which testing occurred was also addressed. Two aspects of circadian rhythmicity which may affect an athlete's performance are circadian range (time-dependent change in the levels of physiological processes) and circadian amplitude (change from mean level to peak level of the rhythm) (Winget, DeRoshia, & Holley, 1985). Due to these processes, individuals experience optimal performance potential at specific times during the course of a day. In light of these variables, and the fact that everyone could not be tested at their optimal performance potential, individuals from the same group were tested at different periods throughout the day in an effort to balance out potential differences in performance created by the subjects' rhythms (Jehue, Street, & Huizenga, 1992; Winget et. al., 1985).

Since the ODP soccer camp was conducted in Bozeman, MT, at an altitude of 4850 feet (1478 meters), the effects of altitude were also a concern. The decrement of aerobic work capacity is approximately 4 to 6% at altitudes of 1200 to 1500 meters (Balke, Nagle, & Daniels, 1965; Squires & Buskirk, 1982). While results from altitude studies indicate that a 10-day acclimatization period is recommended to elicit aerobic values similar to sea level performance by individuals traveling from sea level to altitudes of 2100 meters or higher, subjects were only available for testing over a five day period. Also, differences in aerobic performance have not been observed in subjects tested between a two to four day time period at higher altitude (Adams, Bernauer, Dill, & Bomar, 1975; Balke et al., 1965). Thus, because Bozeman's altitude is less than elevations described in acclimatization studies, but still sufficient to influence aerobic response, aerobic testing was conducted no earlier than 48 hours following the arrival of subjects from elevations close to sea level. Subjects arriving from higher elevations were tested prior to lower altitudes competitors.

Due to the extensive travel necessary to participate in the ODP camp, consideration was also made for the effects of jet-lag due to transmeridian travel. Studies conducted on the effects of jet-lag have suggested that three or more time zones must be crossed before individuals experience the effects of jet-lag, such as an offset in internal rhythms (i.e., sleep-wake cycle) influenced by external cues (i.e., light-dark cycle). Such effects may produce symptoms of insomnia, poor mental and psychological task performance, reduced appetite, fatigue, apathy, weakness, and headaches. Jet-lag primarily affects performance on tests involving the aerobic system (Jehue et al., 1992; Winget et al., 1985). It has also been noted that it takes approximately 24 hours per time zone, when traveling eastward, for the body to fully adapt to the new conditions (Jehue et al., 1992; Loat & Rhodes, 1989). Thus, athletes arriving at ODP camp from three or more time zones away were not tested aerobically until 4 days after arrival to allow for resynchronization of the circadian rhythm (Jehue et al., 1992; Winget et al., 1985).

Criteria for exclusion from the study involved the acknowledgement, complaint, or observed evidence of any medical or orthopaedic problem severe enough to disrupt an athlete's performance or endanger his health. These problems were determined by the parents, athletes, and primary investigator. The parents and athletes were asked to report any previously existing condition of which they were aware, and the primary investigator (a certified athletic trainer) conducted a pre-participation health screening and injury-specific evaluation tests. Subjects were allowed to participate in the study following parental consent and the athlete's consent to the testing instructions.

Upon selection for the study, each individual was instructed to abstain from large meals, any drinks containing caffeine, as well as any physical activity beyond that required by camp, prior to testing. For meals other than those affected by testing, subjects were asked to maintain a high carbohydrate diet to aid the body in the replacement and maintenance of muscle glycogen. Subjects were also instructed to get a good night's sleep prior to testing and to wear soccer clothes, with running shoes for the laboratory tests and soccer cleates for the field tests.

Anthropometric Status

Body composition was determined utilizing both hydrostatic weighing technique and skinfold procedures (Katch, Michael, & Horvath, 1967; Jackson & Pollock, 1977). All anthropometric testing was conducted in the Marga Hoseaus Physical Education Complex pool area at Montana State University.

Skinfold measurements were conducted using the seven site technique (Jackson & Pollock, 1977) using calibrated Lange calipers (Cambridge Scientific Industries, Inc., Cambridge, MD). Each site was measured according to standard anatomical landmarks, which were marked with a pen to insure accuracy of instrument placement. In accordance with standard procedures, three measurements were obtained at each site on the right side of the body, with the mean value from each site added together for the sum total (Jackson & Pollock, 1977). The formula used with skinfold values for the calculation of body density (D_b) was as follows (Jackson & Pollock, 1978):

$$D_b = 1.112 - 0.00043499\,[\text{sum of seven sites}] + 0.00000055\,[\text{sum of seven sites}^2] - 0.00028826\,[\text{age}]$$

Where:

1.112	=	standardized regression coefficient to account for variance of body circumference
0.00043499	=	standardized regression coefficient to account for variance of sum of skinfolds
0.00000055	=	standardized regression coefficient to account for variance of sum of skinfolds squared
0.00028826	=	standardized regression coefficient to account for variance of age

To conduct the hydrostatic weighing, the subject stepped down into the pool, thoroughly soaked his hair and swim suit, and briefly submerged underwater to eliminate air bubbles. When the subject reemerged, he was then instructed to sit on a seat attached to a Chatillon model 114508 scale (John Chatillon and Sons, Inc., Kew Gardens, NY). Upon command, the subject flexed at the hip while seated, submerged himself underwater, and attempted to exhale completely in a controlled manner. The subject temporarily remained still underwater at full expiration to ensure settling of the scale for an accurate reading of his weight in water, measured in kilograms. Five to ten trials were performed, with the highest value (obtained at least twice) used as the subject's "true" underwater weight (Katch et al., 1967).

To determine body density (D_b) from standardized equations used in hydrostatic weighing, residual volume (RV) for each subject was calculated from their vital capacity (VC) measurements collected with a Vacumed model 16800 Zebra spirometer and computer software (Vacumetrics Inc., Ventura, CA) by standard spirometric techniques (Wilmore, 1969; McArdle et al., 1991). The subject wore a nose clip and performed a maximal inspiration followed by a maximal forced expiration into the spirometer. The formula used to calculate residual volume was as follows:

Residual Volume (L) = VC (L) x .24 x BTPS conversion factor

Where:	VC (L)	=	vital capacity in liters
	.24	=	constant used to control for anatomical dead space
	BTPS conversion factor	=	value for conversion from ATPS to BTPS using room temperature

Body density (D_b), percent body fat (BF), and lean body mass (LBM) in kilograms were then calculated according to accepted procedures using the hydrostatic weighing data (Brozek, Grande, Anderson, & Keys, 1963; Goldman & Buskirk, 1961):

$$D_b = \frac{\text{weight of subject in air (kg)}}{\frac{\text{weight in air (kg) - weight in water (kg)}}{\text{density of water}} - [\text{residual volume} + .01L]}$$

Body Fat % = $(457/D_b) - 4.142 \times 100$

Lean Body Mass (kg) = (100 - %BF) x body weight (kg)

Where:	weight in air (kg)	=	weight of the subject in air
	weight in water (kg)	=	weight of the subject in water
	.01	=	constant value used to control for air remaining in intestinal tract
	457	=	constant value used for "obesity tissue"
	4.142	=	constant value used for "fat-free mass"

Aerobic Power

Aerobic power was determined by having a subject complete a maximal GXT using the Bruce treadmill protocol (Bruce et al., 1973). Prior to testing, the subject's age was recorded, and height (cm) and weight (kg) were determined using a Detecto model 437S (Detecto, Webb City, MO) calibrated scale. Room temperature, barometric pressure, and relative humidity were recorded for subsequent ventilatory and metabolic calculations. These values ranged between 22-25°C, 638-650 mm Hg, and 37-56%, respectively.

A pretest was performed to prepare each subject for the GXT. For optimal conductivity, each subject's chest was shaved if necessary and then debrided with gauze and alcohol. Following electrode placement and ECG lead attachment in accordance with the Mason-Likar modified 12-lead protocol for stress testing (American College of Sports Medicine, 1991), supine, hyperventilation, and standing ECG readings were recorded on a Marquette Max-1, 12-lead electrocardiograph (ECG) (Marquette Electronics, Milwaukee, WI). Concomitant blood pressure measurements were also obtained in the supine and standing position. The subject was cleared for testing if cardiorespiratory response did not indicate any contraindications to exercise according to the ACSM guidelines for stress testing (American College of Sports Medicine, 1991).

The subject began the GXT with a one minute warm-up at 0% grade and 1.7 mph on a SensorMedics^R Series 1900 treadmill (SensorMedics Corporation, Yorba Linda, CA) and progressed through subsequent stages of exercise until he reached fatigue (or until he stopped the test by grabbing the front rail of the treadmill). ECG recordings, ratings of perceived exertion (RPE), and blood pressures were taken during the last 30 seconds of each stage during the exercise test and throughout each minute of recovery.

Ventilatory and metabolic expiratory values, i.e., aerobic power (VO_{2max}), ventilation (VE_{max}), and respiratory exchange ratio (RER), were determined breath by breath during exercise and throughout recovery with a calibrated SensorMedics^R 2900 metabolic measurement cart (SensorMedics Corporation, Yorba Linda, CA). The cart was autocalibrated using gases of known concentrations. V-slope method was used to determine the subject's anaerobic threshold (Beaver, Wasserman, & Whipp, 1986). This method notes the beginning of that intensity of work load or oxygen consumption in which anaerobic metabolism is accelerated (Fox et al., 1989). The subject's maximal time ($Time_{max}$) on the treadmill was also recorded.

<u>Anaerobic Power and Capacity</u>

Anaerobic power and capacity were determined by having each subject perform a 30-second Wingate anaerobic test using a calibrated Monark[R] 818E cycle ergometer (Monark AB, Varberg, Sweden) with integrated laser-based sensor and computer software (Sports Medicine Industries, Inc., St. Cloud, MN). Prior to test initiation, seat height was adjusted for the subject to ensure proper knee positioning at approximately 15° of knee flexion with the foot at the bottom of the pedal revolution and parallel to the floor. A warm-up consisted of 6 minutes of 30-second progressive workloads (i.e., 25%, 50%, 75% of test resistance), alternated with 30-second intervals of recovery (pedaling at 300 kpm/min or 1 kp). According to procedures described by Bar-Or (1987), the test resistance was calculated by multiplying the subject's body weight (kg) by .075 kp. At the initiation of each test, the investigator quickly increased the resistance to the calculated workload and simultaneously gave the cue for the subject to pedal with maximal exertion (Bouchard et al., 1991; Tharp, Newhouse, Uffelman, Thorland, & Johnson, 1985). Throughout the test, the investigator gave strong verbal encouragement. At the completion of the 30-second test, recovery was attained by having the subject continue to pedal at approximately 1 kp for 4 minutes, or until the individual was sufficiently cooled-down.

Variables included in the calculation of power output and rate of decline were the subject's performance and weight, the resistance added to the flywheel, the length of the test, and the circumference of the wheel. An electronic sensor counted the number of flywheel revolutions achieved during the test. Mean power (MP), peak power (PP), total work output (TWO), and fatigue index (FI) were calculated according to accepted procedures (Ayalon, Inbar, & Bar-Or, 1974; Bar-Or, Dotan, & Inbar, 1977):

$$MP = \frac{\text{revs x circum (6m) x resistance (kg) x 2}}{\text{body weight (kg)}} = \text{kgm}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$$

$$PP = \frac{\text{revs x circum. (6m) x resistance (kg) x 12}}{\text{body weight (kg)}} = \text{kgm}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$$

These numbers were then converted to watts/kg as follows:

$$W\cdot kg^{-1} = \_\_\_\_ \ \text{kgm}\cdot\text{min}^{-1}\cdot\text{kg}^{-1} \times \frac{\text{1 watt}}{\text{6.12 kgm}\cdot\text{min}^{-1}}$$

Where:			
	revs	=	# of revolutions of the wheel during the test
	circum (6m)	=	circumference of the wheel
	resistance (kg)	=	weight added to the flywheel as determined by the subject's weight
	2	=	constant which converts values based on a 30 second interval to one minute
	12	=	constant which converts values based on a 5 second interval to one minute
	6.12	=	regression number which allows for conversion from $kgm\cdot min^{-1}$ to watts

Total work output and fatigue index were calculated as follows:

$$TWO = \_\_\_\_\text{kgm/min/kg} \times \frac{\text{1 watt}}{\text{6.12 kgm}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}} \times \frac{\text{.06 kJ}}{\text{1 watt}} \times \frac{\text{1000J}}{\text{1 kJ}} = \_\_\_\_\_\_\text{J/kg}$$

$$FI\ \% = \frac{\text{(peak power - lowest power in 5 seconds)}}{\text{peak power}} \times 100$$

Muscular (Leg) Power

Leg power was determined by having each subject perform a vertical jump test which included both squat and countermovement techniques. The squat jump consisted of a static hold of the body prior to take-off with the knees flexed to 90°, and the countermovement jump consisted of a dynamic knee bend to 90° of flexion from a standing position just prior to jumping (Vandewalle, Peres, & Monod, 1987). The subject performed two practice jumps prior to testing to ensure proper jumping technique.

Prior to testing, the subject's standing height was marked on the wall. To accomplish this, the subject stood with his heels flat on the floor and his shoulders perpendicular to the wall. He then reached as high as possible with the wall-side hand to make a chalk mark on the wall. The subject then performed three trials of both jumps, each time placing chalk on his fingertips and making a mark on the wall at the height of each jump. He kept the hand used to mark the jump extended straight overhead, and the opposite hand placed in the small of the back. This was to ensure the use of muscles limited to the lower extremities (Johnson & Nelson, 1986). Jump height was determined using a measuring tape adhered to dark paper on which the subject's chalk prints were clearly evident. Power was calculated using both the Lewis (Semenick, 1984) and Harman (Harman, 1991) standardized regression equations:

$$\text{Power (Lewis)} = (4) \times (\text{Wt}) \times (\sqrt{\text{Ht}}) = \_\_\_\_\_\_ \text{ft-lbs/sec}$$

$$\text{Power (Harman)} = (61.9 \times \text{Ht}) + (36.0 \times \text{Wt}) - 1{,}822 = \_\_\_\_\_ \text{watts}$$

Where:

	4	=	value used for estimation of speed in jump performance
	$\sqrt{\text{Ht}}$	=	square root of height in feet
	1.355	=	regression number which allows for conversion from ft-lbs/sec to watts
	61.9	=	regression coefficient for the variance in jump height due to gravity's effect on body mass
	Ht	=	height of the jump in centimeters
	36.0	=	regression coefficient for the variance of total body center of mass
	1,822	=	regression coefficient for the variance in vertical ground reaction force
	Wt	=	weight of subject in kilograms

The values for both the Lewis (Semenick, 1984) and Harman (Harman, 1991) nomograms were converted to W/kg for reporting and comparative purposes:

$$W/kg\ (Lewis) = \frac{ft\text{-}lbs/sec \times 1.355}{Wt\ (kg)} \qquad W/kg\ (Harman) = \frac{watts}{Wt\ (kg)}$$

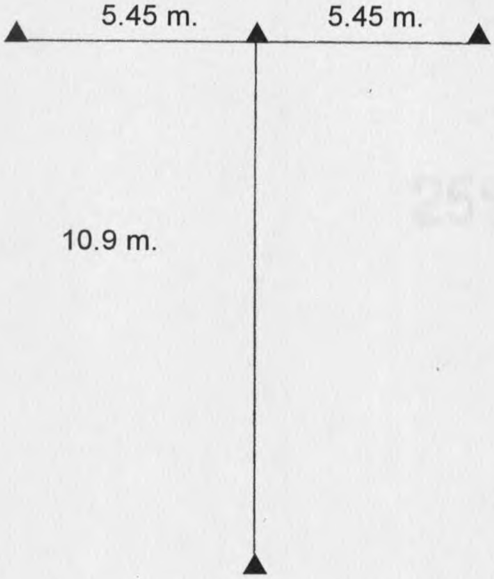
Agility

Agility was determined by having each subject complete a T-test (Semenick, 1990b) and a line drill test (Semenick, 1990a). The T-test, as shown in Figure 1, was conducted on a grass practice field using four cones, a stopwatch, and a recorder. The cones formed the shape of a T with the top three cones 5.45 meters apart, and the fourth cone (forming the base of the T) exactly 10.9 meters perpendicular to the center cone.

The test consisted of 5 minutes of warm-up and stretching of the subject's choosing, followed by one trial run and three timed runs. Upon starting, the subject ran from the base cone (A) to the center cone (B), shuffled left 5.45 meters to cone C, shuffled right 10.9 meters to cone D, shuffled left 5.45 meters back to cone B, and then backpedaled 10.9 meters to the start/finish line (cone A). The time of all three trials were recorded with the best time used for data analysis.

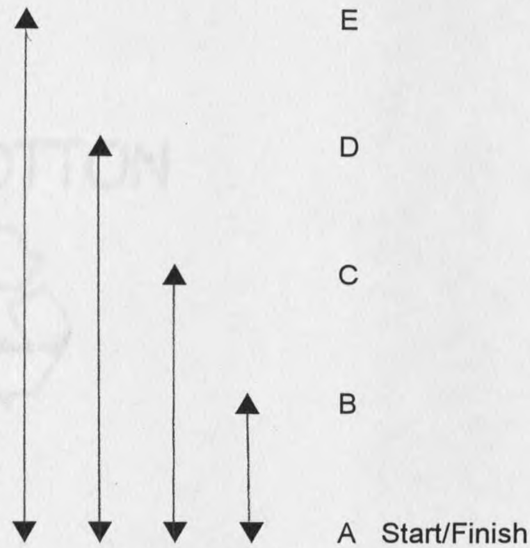
The line drill test, as shown in Figure 2, was conducted on a practice field using five cones and a timer with a stopwatch. The first cone (A) indicated the start/finish line, and the other four cones were placed in a straight line exactly 5.79 meters (cone B), 12.80 meters (cone C), 19.81 meters (cone D), and 25.60 meters (cone E), respectively, from the starting line. The subject performed four trials, running straight from the starting line to the second cone (B) and back, then to the third cone (C), fourth (D), and fifth (E) cones in a shuttle fashion, touching the line or respective cone with one hand each time. The course was completed by running back to the finish line from the fifth cone where a tester stopped the time. The time was recorded for each trial with the average time of the four trials used for data analysis.

Figure 1. T-test



Adapted from Semenick, D. (1990b). The T-test. National Strength and Conditioning Association Journal, 12(1), 36-37.

Figure 2. Line Drill Test



Adapted from Semenick, D. (1990a). The line drill test. National Strength and Conditioning Association Journal, 12(2), 47-49.

Sport Skill

Sport skills specific to soccer were assessed using three procedures conducted on a grass practice field. The procedures used were the juggling test, to determine ball control (Baumgartner & Jackson, 1987), the Johnson wall volley, to assess kicking accuracy and trapping ability (Collins & Hodges, 1978), and the modified-Zelenka test, a circuit drill used to evaluate ball control, shooting ability, and the ability to maneuver oneself around or between defenders (Nettleton & Briggs, 1980).

The juggling test was conducted by having a subject drop a ball to one knee or foot, and then without the use of arms or hands, tap the ball in the air as many times as