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Bioenergetics and time-motion analysis of competitive basketball

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BIOENERGETICS AND TIME-MOTION ANALYSIS OF COMPETITIVE BASKETBALL

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Basketball has been considered to require players to employ extensive amount of energy throughout games. However, research findings regarding bioenergetic traits and demands of actual basketball performance has been considerably limited. The purpose of this study was to describe and assess bioenergetic traits of actual basketball performance in collegiate female and male players by measuring oxygen consumption (VO2), heart rate (HR), blood lactate concentration (BLC), as well as rating of perceived exertion (RPE), and performing a time-motion analysis in team scrimmages.

Six female and six male collegiate basketball players (20.0 ± 1.2 and 20.8 ± 0.9 years old, respectively) were asked to play team basketball scrimmages while wearing portable measurement systems. VO2 and HR were measured by the portable systems during play, and BLC and RPE were measured during alternate resting periods. Additionally, the subject's performance was videotaped throughout the scrimmage to conduct time-motion analysis.

The female and male players demonstrated mean VO2 values of 33.4 ± 3.6 and 37.0 ± 2.4 ml/kg/min, respectively during play; while mean BLC values were 3.2 ± 0.8 and 4.1 ± 1.2 mmol/L, respectively. They spent 34.1 % of play time performing active movements while 56.9 % of time walking and 9.0 % standing. No significant differences were observed between the females and males in the variables measured ($p > 0.05$), except that the males expended significantly greater energy through the scrimmages (49.2 %; $p \leq 0.05$). $VO2_{max}$ values obtained from a preliminary testing were significantly correlated to VO2 during play ($r = 0.673$ for all subjects; $p \leq 0.05$) and percent of duration for active movements during play ($r = 0.936$ and 0.962 for the females and males, respectively; $p \leq 0.05$). These results suggest that female and male collegiate basketball require extensive utilization of aerobic metabolism during play and enhancement of aerobic capacity may be beneficial to improve the quality of performance in basketball. In conclusion, this study revealed greater oxygen cost playing basketball than previously expected and demonstrated other specific bioenergetic traits of female and male collegiate basketball.

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Chapter 1 – Introduction

Basketball has gained worldwide popularity and has fascinated players and spectators with its dynamic characteristics as a team sport (Hoffman & Maresh, 2000). This sport consists of a variety of multidirectional movements such as running, dribbling, and shuffling at variable velocities and jumping. To execute such movements during performance, both anaerobic and aerobic metabolic systems are expected to occur throughout a game (Ciuti et al., 1996).

Up to this point, many studies have been performed to describe general traits of this sport and its athletes. For instance, Blake (1941) demonstrated that male collegiate basketball players covered 2 km during defensive play in games. Also, Crisafulli et al. (2002) presented a study that basketball players covered an average of 4,500 to 5,000 m of distance during a game and about 11 % of the total time consists of high intensity anaerobic actions lasting less than 20 seconds. Furthermore, Latin, Berg and Baechle (1994) and LaMonte, McKinney, Quinn, Bainbridge and Eisenman (1999) demonstrated anthropometric and physiological characteristics of NCAA (National Collegiate Athletic Association) Division I male and female basketball players, respectively.

Many research groups (Button, MacLeod, Sanders & Coleman, 2003; Crisafulli et al., 2002; McClay et al., 1994) have also tried to gain specific insights into the nature of this sport and provide meaningful information to basketball coaches, strength and conditioning coaches, and athletic trainers, as well as players. For example, McClay et al. (1994) examined 24 NBA players using kinetic and kinematic measurements to identify biomechanical characteristics relevant to typical injuries in basketball. They speculated that several common movements in basketball such as the landing after lay-up, cutting, and shuffling caused much higher knee flexion velocity and/or ankle supination than normal landing from running and may induce typical injuries including patellar tendonitis and ankle sprains. Button et al. (2003) assessed the kinematic characteristics of basketball free-throw actions performed by six female players and revealed that improvement of the performance was accompanied with greater consistency in kinematic coordination between the elbow and wrist joints. Crisafulli et al. (2002) integrated biomechanical and physiological tools to assess the relationship between mechanical work efficiency, an index to judge quality of performance, and CO_2 excess, an index for anaerobic (lactacid) capacity, during a series of intermittent movements that mimicked basketball. They found that these two values were significantly correlated ($r = 0.95$, $p < 0.01$) and concluded that high anaerobic capacity may be one of the most important aspects of basketball players to achieve required performance.

However, in spite of a fair volume of studies conducted for this sport so far, scientific findings regarding bioenergetic traits and demands of *actual* basketball performance have been still limited (Ciuti et al., 1996; Crisafulli et al., 2002; Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce & Terrados, 2003). One of the biggest limitations is that most previous studies were conducted in laboratory settings using some fitness tests (Ciuti et al., 1996; McClay et al., 1994) or on the court using isolated tasks that mimic basketball (Button et al., 2003; Crisafulli et al., 2002). Consequently, these studies did not address actual traits and demands of basketball performance during game play. Conducting studies on the court with more realistic task settings (e.g., games and scrimmages) is essential for better understanding the unique bioenergetic demands of this sport.

Two research groups have recognized this problem and they tried to address it by examining true basketball performance to obtain direct findings about its bioenergetic demands. Rodriguez-Alonso et al. (2003) tried to quantify the intensity of female basketball games with physiological variables including heart rate (HR) and blood lactate concentration (BLC). McInnes, Carlson, Jones and McKenna (1995) demonstrated the physiological and bioenergetic aspects of male basketball games by measuring HR and BLC, as well as performing time-motion analysis. While both studies seem to succeed in partially depicting bioenergetic traits and demands of actual basketball performance, they still lack direct assessment for aerobic metabolism due to the absence of direct measurement of oxygen consumption. To bring more meaningful information into the practical field, a more complete assessment including both aerobic and anaerobic observations should be conducted for actual basketball performance. Fortunately, the latest technology allows measurement of oxygen consumption in actual performance by using portable systems. Therefore, the purpose of this study was to describe and assess bioenergetic traits of actual basketball performance in collegiate female and male players by measuring oxygen consumption (VO2), HR, BLC, as well as perceived exertion (RPE), and performing a time-motion analysis in team scrimmages. Scrimmages were conducted with the NCAA Division II players and administered in the same way as actual games with cooperation of all players, coaches, referees, and scorers to simulate true game conditions.

Chapter 2 – Problem

Purpose

The purpose of this study was to describe and assess bioenergetic traits of actual basketball performance in collegiate female and male players by measuring VO2, HR, BLC, as well as RPE, and performing a time-motion analysis in team scrimmages.

Hypotheses

1) Competitive collegiate basketball requires players to employ a greater level of aerobic metabolism during play to demonstrate quality performance than previously thought. Specifically, mean VO2 in both female and male groups will be higher than 8.0 METs (metabolic equivalent; 28.0 ml/kg/min), which was estimated by Ainsworth et al. (2000) based on the findings of multiple studies using self-reports.
2) There are different bioenergetic traits between female and male competitive collegiate basketball. Specifically, significant differences will be demonstrated between female and male groups on VO2, HR, BLC, and/or RPE during play, as well as other variables derived from the above measurement and time-motion analysis, such as mean energy expenditure (EE) and percent of duration for active movements (PAM) during play.
3) Bioenergetic traits are altered in accordance with the duration of play in competitive collegiate basketball mainly due to fatigue. Specifically, significant differences will be observed among four different playing periods in the scrimmages on VO2, HR, BLC, RPE, and/or PAM for respective playing periods.
4) Similar to the previous findings in conventional experimental tasks (Foss & Keteyian, 1998), variance of exercise intensity is explained by that of bioenergetic/physiological

responses in competitive collegiate basketball. Specifically, significant relationships will be found between an indicator of the exercise intensity (i.e., PAM) and VO2, HR, and/or BLC playing basketball.

Delimitations

Six female and six male basketball players of the University of Nebraska at Omaha (UNO) men's and women's basketball teams volunteered to participate in this study. Within three weeks after the completion of the 2004-2005 season, both the female and male teams played regular basketball in six team scrimmages, respectively. Each scrimmage was designed to mimic one-half of an official game and to consist of four playing periods (PPs) of about five minutes each and alternate resting periods (RPs) of about one minute each. The scrimmage was administered in the same way as actual games with cooperation of all players, coaches, referees, and scorers. In each scrimmage, a single subject was assigned for data collection in advance. From the subject, VO2 and HR were recorded by portable measurement systems throughout the scrimmage, and BLC and RPE were measured by an investigator right after the beginning of each RP and immediately after the completion of the scrimmage. Additionally, the subject's performance was videotaped throughout the scrimmage for subsequent time-motion analysis. Within one to three days before the scrimmage, each subject was asked to perform preliminary tests to determine height, body weight, body fatness, and maximal aerobic capacity ($VO2_{max}$), as well as to familiarize the subject with wearing a portable metabolic measurement system. All the field testing (i.e., scrimmages) were performed at the UNO Sapp Field House or the HPER Building and all the preliminary testing were performed at the UNO HPER Exercise Physiology Laboratory.

Limitations

One primary limitation, which usually exists in all field studies, was that the investigator may not be able to clearly identify and control all extraneous variables that may affect performance. For instance, environmental conditions including air temperature and humidity, as well as physical conditions of all participants may be different among respective scrimmages and such differences may alter the traits of the scrimmages (e.g., tactics and intensity). To minimize this limitation, all scrimmages were scheduled for the same time period across the experimental days for respective teams. Additionally, sufficient interval time (about 20 minutes) was set between scrimmages performed in the same day. Another possible limitation was that the portable metabolic measurement system employed in this study may have bothered the subjects and interfered with their original performance. This system may also have negatively affected performances of other players (i.e., teammates and opponents), and consequently, have altered the nature of game play. This limitation was minimized by devising optimal fitting techniques in advance through pilot trials. Also, the subjects were allowed to have enough time in the preliminary tests to familiarize themselves with the devices. The last possible limitation was that the subjects may not exhibit their maximal effort during the scrimmage. As one study demonstrated (Rodriguez-Alonso et al., 2003), exercise intensity during scrimmages seems to be lower than that in actual games. However, this limitation was minimized by emphasizing the importance of maximal efforts in prior explanation to the subjects, as well as by creating realistic and competitive atmosphere with the presence of coaches and use of referees and scores in the scrimmages.

Definition of Terms

Bioenergetics: The biology of energy transformations and energy exchanges within and between living things and their environments (Merriam-Webster Online Dictionary, 2005). In this study, this term was used mainly to denote traits of both aerobic and anaerobic energy systems in basketball and its players.

Blood lactate concentration (BLC): The density of lactic acid (lactate), a fatiguing metabolite produced during anaerobic glycolysis (Foss & Keteyian, 1998), in a given blood sample. This variable is considered to indicate the degree of anaerobic (glycolytic) metabolism in a given exercise. The unit of mmol/L is generally used for this variable.

Oxygen consumption (VO2): The amount or rate at which oxygen can be consumed per minute (Foss & Keteyian, 1998). This variable is considered to indicate the degree of aerobic (oxidative) metabolism in a given exercise. The unit of ml/kg/min is generally used for this variable.

Ratings of perceived exertion (RPE): The rating of the degree of physical strain an individual feels at a given exercise intensity. The rating with Borg's RPE scales has been widely used in both field and laboratory settings to quantify exercise intensity (Borg, 1998).

Time-motion analysis: A standard analytic procedure for classifying the types of activities in a given task and for quantifying the frequency and duration of these activities over a period of time. Video images are typically used for this analysis. In this study, the time-motion analysis was performed to quantify the traits of actual basketball performance during team scrimmages.

Significance of Study

Conducting holistic investigation for actual basketball performance is essential to provide more meaningful applicable findings and implications for coaches and exercise specialists, and furthermore, to facilitate bridging a gap existing between the scientific and practical domains. Although several research groups have performed studies to depict unique bioenergetic traits and demands of basketball, they failed to employ realistic task settings and/or appropriate direct measurements. This study was unique since the bioenergetics of basketball was addressed not only in realistic task settings (i.e., team scrimmages) but also with both aerobic and anaerobic measurements and time-motion analysis. This study may contribute to the development of sound training programs for basketball players which are essential to promote physical conditioning, and consequently, to improve quality of performance.

Chapter 3 – Review of Literature

Introduction

For any sport activities, the concept of specificity may be one of the biggest considerations for the coaches when designing practice and strength and conditioning programs to enhance sport-specific performance (Baechle & Earle, 2000). Bioenergetics in sports is one concern in this concept. To bring scientific knowledge regarding the specificity of basketball, many investigators have described the traits of this sport and characteristics of the players with a variety of assessments. The present study was also performed to clarify the bioenergetic traits of basketball performance during team scrimmages from the combination of aerobic and anaerobic assessment and time-motion analysis.

To understand the present status of investigations for basketball, especially of those relevant to bioenergetic traits of this sport, as well as to attain fundamental and beneficial knowledge to design the present study, a review of literature was presented in this chapter. Specifically, selected articles were reviewed and discussed in the following three categories: 1) physical and physiological profiles of basketball players, 2) time-motion analysis of basketball performance, and 3) assessment of bioenergetic demands in basketball performance.

Physical and Physiological Profiles of Basketball Players

Up to this point, many studies have investigated physical and physiological profiles of basketball players according to gender, age, position and competitive level and compared their profiles. Comparisons have also been made across several time periods in a season and/or with athletes in other sports and non-athletes. Conventional measurements and field tests have been typically employed in these studies. Although the aim of most studies seemed to be mainly to draw a general picture (i.e., demography) of basketball players, some of the studies have tried to speculate about the nature of basketball performance and/or its physiological demands from the results. In the first part of this section, survey and demographic studies for collegiate basketball players were reviewed. Then, studies addressing changes of physical and physiological profiles within and across basketball seasons were discussed. Additionally, one study that examined relationship between these profiles and a performance outcome (i.e., playing time in season games) was discussed.

Survey and Demographic Studies

Latin et al. (1994) conducted a comprehensive survey to describe anthropometry and physical fitness of top collegiate male basketball players. Forty-five NCAA Division I men's basketball teams responded to their request and a total 437 players in these teams (within ten players on each team) were surveyed about their body composition, muscular strength, speed, power, agility and aerobic capacity. Although sample sizes differed between variables, mean and standard deviation values for major variables were as follows (M ± SD): height, 195.3 ± 8.9 cm; weight, 91.3 ± 11.1 kg; percent body fat, 9.4 ± 15.2 %; vertical jump 71.4 ± 10.4 cm; 1-RM (repetition maximum) bench press, 102.7 ± 18.9 kg; 1-RM squat, 152.2 ± 36.5 kg; 40-yd dash, 4.81 ± 0.26 sec; agility (score of T-test, a agility test including a series of forward sprint, side shuffle, and backward run), 8.95 ± 0.53 sec; and 1 mile run, 340 ± 32 sec. The investigators compared these results between positions (i.e., guards, forwards and centers) and found that there are significant differences between the positions in all the variables except 1-RM bench press and agility ($p \leq 0.01$). Although they are not necessarily based on the statistical analyses, the investigators depicted characteristics of the players in each position as follows: guards were the smallest and leanest players and had the best power, speed and strength relative to body weight and the best 1 mile run performance; centers were the largest players and had the highest percent body fat, lowest speed and agility, and slowest 1 mile run time; forwards took a middle position between guards and centers in most variables but had greater strength in lower extremities than centers. Also, significant differences were found between teams in all the above variables except for height and weight ($p \leq 0.01$). From these results, the authors speculated that these variations may be due to different physical and physiological demands for each position and differences of tactics, play style, and/or recruitment strategy.

The same research group also compared selected variables, height, weight, percent body fat, vertical jump, 40-yd dash, 1-RM bench press, and 1-RM squat scores, from the above investigation with those from a similar survey for 880 players in forty NCAA Division I football teams to obtain further knowledge with respect to the unique physical qualities in both sports (Berg & Latin, 1995). They found significant difference between the two groups in all variables except the 40-yd dash ($p \leq 0.01$). Based on this comparison, they depicted that the basketball players were 4.4 % taller and 14.0 % learner and had 30.9% less fat than the football players. They also shared equivalent level of speed with the football players, while the football players had considerably higher power and muscular strength. The authors suggested that the differences between the athletes of the two sports are mainly due to the differences of physical and physiological demands (e.g., energy exertion in longer traveling distance and higher work-rest ratio for basketball versus the more explosive manner in lower work-rest ratio for football), differences of typical training protocols, and/or a combination of the two factors.

Gillam (1985) examined thirteen male basketball players in a NCAA Division II basketball team within two weeks after the last competitive game in the season. Fifteen variables were selected and measured to demonstrate their anthropometric and physiological profiles. The following results were revealed (M ± SD): height, 189.2 ± 7.0 cm; weight, 86.0 ± 8.7 kg; lean body mass, 74.4 ± 7.3 kg; fat mass, 11.63 ± 2.9 kg; percent body fat, 13.5 ± 2.8 %; 1-RM bench press, 76.3 ± 11.3 kg; 1-RM squat, 115.3 ± 18.0 kg; push-ups, 23.2 ± 7.9 reps; squat thrust, 58.5 ± 31.2 reps; 12 minute run distance, 2,613.1 ± 350.8 m; power (derived from vertical jump score), 154.1 ± 16.4 kgm/sec; acceleration (15-yd run), 2.33 ± 0.1 sec; speed (50yd run after 15-yd run), 5.3 ± 0.3 sec; agility (right-boomerang run), 10.8 ± 0.3 sec; and flexibility (sit and reach test), 29.3 ± 8.8 cm. They also compared these results with those of fourteen physical education students from the same generation and found that the basketball players were significantly taller and had higher lean body mass, squat thrust reps, and power and greater acceleration, speed, and agility times ($p \leq 0.05$). The author suggested that the relevance of speed and agility for participating in basketball was evidenced by the superior speed, acceleration and agility scores of the basketball players and these variables should be taken into account when developing training programs, as well as when conducting member selection.

LaMonte et al. (1999) employed larger number of female basketball players than any other previous studies to describe their physical and performance traits. Forty-six female basketball players were recruited from a NCAA Division I team during an eight-year period. Selected variables and results of this study were as follows (M ± SD): height, 177.5 ± 8.2 cm; weight, 70.4 ± 9.3 kg; fat-free mass, 58.1 ± 5.8 kg; percent body fat, 17.0 ± 5.1 %; vertical jump, 48.2 ± 8.5 cm; and peak and mean powers (from Wingate Anaerobic Test), 663.5 ± 93.8 W and 498.0 ± 51.3 W, respectively. The authors also compared these variables between positions (i.e., guards, forwards and centers) and found the following results: the centers were significantly taller and heavier than the forwards ($p \leq 0.05$), and the forwards were significantly taller and heavier and had greater fat-free mass than the guards ($p \leq 0.05$); there were no significant differences between positions in vertical jump score and peak and mean powers ($p > 0.05$); the forwards and guards had significantly higher peak and mean powers relative to body weight than the centers ($p \leq 0.05$). The trends of results in anthropometry were similar to those for male basketball players (Latin et al., 1994). That is, the centers and guards were at the extremes of most variables (i.e., highest and lowest) and the forwards had intermediate values. Although the meaning of significant differences in the peak and mean powers relative to body weight were not fully interpreted, the authors concluded that significant differences of performance traits including anaerobic power profiles were not observed between positions in female basketball players.

Changes of Profiles within and across Basketball Seasons

To explore deeper insights into the nature of basketball performance and/or its physiological demands, several research groups have observed changes of players' physical and physiological profiles within and across basketball seasons. In some of these studies, a series of basketball games in a season seemed to be regarded as a primary intervention which alters these profiles.

Hunter, Hilyer and Foster (1993) tried to examine changes of anthropometry and performance profiles in collegiate male basketball players during their college basketball career. The following variables were selected and measured for this analysis: body weight, percent body fat, lean body weight, maximal aerobic capacity ($VO2_{max}$), 1-RM bench press, 1-RM squat, sit-and-reach flexibility, vertical jump, and peak and average power during vertical jump. During seven years, the difference between freshmen and sophomores, sophomores and juniors, and juniors and seniors with respect to the above variables were assessed with nineteen, seventeen, and sixteen players, respectively. It should be noted that this study did not monitor the same subjects longitudinally. Significant differences were observed in all comparisons for 1-RM bench press and 1-RM squat ($p \leq 0.05$) and in two of the comparisons for weight, lean body weight, vertical jump, and peak and average power during vertical jump ($p \leq 0.01$ for lean body weight between freshmen and sophomores, $p \leq 0.05$ for the rest comparisons). No significant difference was obtained in any comparisons for the body fat, $VO2_{max}$ and sit-and-reach flexibility. The basketball players seemed to considerably improve their lean body mass, muscular strength in both upper and lower body and anaerobic capacity through their college basketball career. The authors mentioned that these changes may be due to the combined effects from strength and conditioning programs, team practice and games, and/or maturation through this period. They also speculated that the basketball career did not require the players to enhance their aerobic capacity, and thus, this capacity may not be a critical factor. They stressed that these results can be useful for coaches when they evaluate the fitness of individual athletes and/or establish realistic goals for them.

To evaluate the effects of both pre-season practice and a basketball season on aerobic fitness, anaerobic fitness, and body composition, Tavino, Bowers and Archer (1995) compared results of fitness testing among three testing phases in a season. Nine male basketball players in a NCAA Division I team were recruited for this study and body weight, percent body fat, $VO2_{max}$, and anaerobic capacity (from anaerobic power step test) were measured for each player in the following three phases: before pre-season practice (phase 1), five weeks after starting pre-season practice (4 days before the first game of the season; phase 2), and a week after the end of season (phase 3). Weekly pre-season practice approximately consisted of aerobic conditioning for five days, weight training for three days, and anaerobic conditioning (basketball drills, team scrimmages, or both of them) for six days. Also, weekly in-season schedule typically included two or three games preceded by relatively light practice sessions and either scrimmages or anaerobic conditioning one to two days. Although it was not clearly mentioned, in-season practice, incorporating games, was probably designed to maintain their aerobic and anaerobic fitness and body composition throughout the season. The results revealed significant reduction of percent body fat between phase 1 and 2 (-26.3 %; $p \leq 0.05$), significant increase of percent body fat between phase 2 and 3 (+20.2 %; $p \leq 0.05$), and significant increase of anaerobic capacity between phase 1 and 2 (+15.9 %; $p \leq 0.05$). Although significant differences were not obtained, the results also showed 4.1 % increase of weight, 5.3 % decrease of $VO2_{max}$, and 0.4 % increase of anaerobic capacity between phase 2 and 3. From these results, it was speculated that change of training format, especially suspension of weight training, induced an increase of percent body fat during the season. Also, based on the results regarding changes of aerobic and anaerobic capacity across the testing phases in the season, the authors presumed that the energy to sustain intermittent high intensity performances in basketball games is derived primarily from anaerobic metabolism.

In order to determine if basketball players can maintain physical conditions achieved by an intensive pre-season conditioning program throughout a basketball season, Hoffman, Fry, Howard, Maresh and Kraemer (1991) compared their strength, speed, endurance, agility and anthropometry between pre- and post-season periods. Nine male basketball players in a NCAA Division I team were asked to participate in this study. Their body weight, skinfold, thigh girth, 1-RM bench press, 1-RM squat, 27m sprint time, 1.5 mile run time, T-test score and vertical jump height were measured before starting a regular season (i.e., just after the completion of pre-season conditioning program) and within two days after the final game in the season. Although the detail of the in-season practice was not fully described, the authors implied that the practice did not include specific conditioning programs to maintain physical fitness gained in the pre-season conditioning. The result revealed that significant impairment was observed only in 27 m sprint time (-3.3 %; $p \leq 0.05$). Although impairment of body weight, skinfold, thigh girth, 1-RM bench press, 1-RM squat, 1.5 mile run time, and vertical jump height were observed (+1.7 %, +7.8 %, -0.2 %, -0.7 %, -4.3 %, -4.9 %, -0.2 %, respectively), they were not statistically significant ($p > 0.05$) and relatively small. The agility score was slightly enhanced (+2.8 %), but the change was not significant ($p > 0.05$). The authors suggested that high intensity and long duration of running, which are inherent to basketball practice and competition, generated an effective stimulus to maintain the above profiles at desirable levels without specific conditioning programs.

Caterisano, Patrick, Edenfield, and Batson (1997) claimed that previous studies assessing effects of a basketball season on players' anthropometric and physical profiles have not considered players' status (i.e., starters vs. reserves) and the results may be somewhat contaminated. To investigate the effects of playing time in official basketball games on the changes of such profiles, the authors measured body weight, percent body fat, $VO2_{max}$, 1-RM bench press and 1-RM leg press for nine starters and eight reserves in a NCAA Division I team a week before starting a season (pre-season) and a week after the season (post-season). The season lasted three months and included 27 competitions at rate of two to three per week. Average playing time in the competitions was 33.5 ± 1.7 minutes in the starters and 3.4 ± 2.5 minutes in the reserves. The results showed no significant difference of body weight and percent body fat in both starters and reserves between pre- and post-season ($p > 0.05$), significant decrease of 1-RM bench press in both starters and reserves (-7.5 %, -11.9 %, respectively; $p \leq 0.05$), significant decrease of $VO2_{max}$ in reserves (-9.7 %; $p \leq 0.05$), and significant decrease of 1-RM leg press in starters (-14.0 %; $p \leq 0.05$). Although significant differences were not obtained ($p >$ 0.05), the results also showed an 1.1 % increase of $VO2_{max}$ in starters and 4.3 % decrease of 1-RM leg press in reserves. Since the starters slightly increased their $VO2_{max}$ throughout the season despite lower volume and intensity of in-season practice, the authors implied that the basketball games including prolonged, high intensity activities present not only anaerobic but also aerobic demands to the players and thus allowed them to maintain aerobic capacity during the season. Based on the results, the authors concluded that players' status (i.e., starters vs. reserves) or playing time in the games is considered a critical factor to determine players' physical profiles and should be taken into account when developing in-season conditioning programs.

Relationships between Profiles and Performance Outcomes

As a part of their study, Hoffman, Tenenbaum, Maresh and Kraemer (1996) tried to examine the utility of fitness testing scores on predicting playing time in the season basketball games. Twenty-nine male basketball players in a NCAA Division I team were involved in this study over the four year period. Fitness testing was performed five days before the start of basketball practice in each season of the period. Fifteen players participated in the testing in multiple years while the rest of the players did in a single year. The testing included 1-RM bench press, 1-RM squat, T-test, 27 m sprint, vertical jump, and 1.5 mile run. For each year, relationships between playing time in the season games and each of the above variables were assessed with the Pearson correlation coefficient. Significant relationships with the playing time were observed in 1-RM squat in two seasons (r = 0.64 and 0.52; $p \leq 0.05$), 27 m sprint in one season (r = -0.62; $p \leq 0.05$), vertical jump in two seasons (r = 0.68 and 0.58; $p \leq 0.05$), and 1.5 mile run in two seasons (r = 0.64 and 0.63; $p \leq 0.05$). Surprisingly, the result for 1.5 mile run showed that players with longer running time (i.e., slower running speed) tend to have more playing time. They concluded that although basketball players may need some extent of aerobic base, further improvement of aerobic capacity may not necessarily be a critical factor to enhance basketball performance and prolong playing time.

Summary

As discussed earlier, many investigators have examined physical and physiological profiles of collegiate basketball players and changes of these profiles within and across basketball seasons. The findings from these studies may provide coaches and other exercise professionals with some general concepts and these concepts may be beneficial when recruiting athletes, establishing team strategies, and/or developing strength and conditioning programs. Some of these studies have also tried to examine the nature of basketball performance and/or its physiological demands based on the results. For instance, the studies reviewed in this section suggested that the nature of basketball performance may allow players to maintain/enhance their lean body mass (Berg & Latin, 1995; LaMonte et al.,1999; Hunter et al., 1993), speed (Berg & Latin, 1995; Gillam, 1985; Hoffman et al., 1996), agility (Gillam, 1985; Hoffman, et al., 1991), muscular strength (Hunter et al., 1993; Hoffman, et al., 1991; Hoffman, et al., 1996), anaerobic capacity (Hunter et al., 1993; Tavino et al., 1995), and aerobic capacity (Hoffman, et al., 1991; Caterisano et al., 1997). However, implications for better understanding the bioenergetics of basketball have been still lacking from these studies. This is simply because all the above suggestions were developed based only on indirect measurements in some experimental tasks and/or fitness tests, and consequently, they are not sufficient to demonstrate the bioenergetic traits in actual game play. To fully investigate the bioenergetics, more sophisticated assessment techniques should be incorporated to perform direct measurement of variables in real basketball performance, such as heart rate, blood lactate level, ATP-PC turnover, oxygen consumption, and so on.

Time-Motion Analysis of Basketball Performance

As discussed in the previous section, the nature of basketball performance and its physiological demands have been examined mostly by relying in physical and physiological profiles and their changes in basketball players. For investigators, such approach is considered feasible to design and conduct. However, since this type of research involves many extraneous variables, it may be difficult to yield rational insights into bioenergetics in basketball performance only from these outcomes. Recently, to investigate the bioenergetics more deeply, several researchers have started performing time-motion analysis for actual basketball performance.

As a part of their comprehensive study, McInnes et al. (1995) conducted a thorough time-motion analysis for basketball during official and practice games. The purposes of their study were to quantify traits of movement patterns in basketball by analyzing video data. Eight male basketball players in the Australian National

Basketball League participated in this study as volunteer subjects. One of the subjects was filmed by a video camera throughout a whole competition or practice game except resting periods between quarters. Total eight games were investigated to obtain image data for all the subjects. After the games, live time (i.e., actual playing time) and total time were determined in each quarter by using the image data collected. Live time was then coded based on the following categories of activities, and frequency and duration of each activity was counted: stand/walk, jog, run, stride/sprint, low shuffle, medium shuffle, high shuffle, and jump. The results of this study clearly demonstrated the intermittent nature of basketball game with a variety of statistics as follows: 997 ± 183 discrete activities with an average 2.0 seconds duration in 36.6 ± 6.5 minutes live time and 63.4 ± 9.9 minutes total time; 105 ± 52 high intensity runs with an average 1.7 seconds duration occurred every 21 seconds in the live time; about 60 % of the live time was spent engaging in low-intensity activities, while only 15 % was used for high-intensity activities.

In a case study, Taylor (2003) also performed a similar time-motion analysis. One male basketball player in a NCAA Division I team, who played the largest number of minutes in official games during two seasons, was videotaped in four official games. Frequency and duration of high intensity efforts and sub-maximal intensity efforts in his movements, intermittent stops in play, and timeouts were counted by using a standardized criterion. From these counts, descriptive statistics were calculated. The results revealed several values with respect to his movement patterns as follows: mean high intensity bouts, 134.8 ± 32.4 per game; mean sub-maximal intensity bouts, 150.3 ± 40.6

per game; 97 % of high intensity bouts occurred at duration within 15 seconds; 94 % of sub-maximal intensity bouts occurred at duration within 20 seconds, 1 intermittent stop occurred after every 11.3 bouts, 1 timeout occurred after every 18.9 bouts. Based on these results, the author strongly recommended basketball coaches to apply such analysis data when developing conditioning programs for players. Moreover, the author provided very practical examples of the application in this study and other study (Taylor, 2004).

As discussed previously, to quantify the traits of performance or movement patterns in actual basketball games, several investigators have performed time-motion analysis. This type of study may produce more clear insights with respect to the specificity of basketball and its bioenergetic demands. However, due to limited number of studies presently published, methodology of the analysis may be still in the process of trial and error, and thus, there seem to be some problems. For instance, although both of the reviewed studies tried to categorize performance by using consistent criteria including both type and intensity of movements, the criteria used were somewhat subjective. Objectivity of the criteria is considered very important not only to justify findings but also to enhance generalization of the findings and methodology. Identifying movement velocity is considered one possible way to objectify the definition of movements in the criteria.

Assessment of Bioenergetic Demands in Basketball Performance

As another approach to attain clearer insights into the nature of basketball performance and its bioenergetics, some investigators have started directly measuring bioenergetic variables during basketball performance and/or alternative tasks. Moreover, a few researchers have conducted time-motion or kinematic analysis simultaneously with bioenergetic measurements to assess their relationship and to speculate about the roles of respective energy systems.

Although one biophysiological study has demonstrated the efficacy of high aerobic capacity in recovery processes from continuous muscular contractions (Idstrom, Harihara Subramanian, Chance, Schersten & Bylund-Fellenius, 1985), such result has not been reported for basketball performance. To investigate relationship between aerobic and anaerobic capacity, fatigue profile, and heart rate recovery profile in high intensity anaerobic exercise, Hoffman, Epstein, Einbinder and Weinstein (1999) performed an experimental study with male basketball players. Twenty basketball players from Israeli national youth and national collegiate teams were recruited one to four weeks after the end of their seasons. They performed a treadmill GXT (graded exercise test), a Wingate anaerobic power test, and three sets of line drill test, a field test common to basketball players, with a two minute rest between two adjacent trials. $VO2_{max}$ were measured in the GXT. Also, the following scores were obtained by the other two tests: peak power (P_{peak}), mean power (P_{mean}), peak heart rate and recovery heart rate from the Wingate test; and sprint time (T_1 - T_3), peak heart rate and recovery heart rate from the each drill trial. A fatigue index in anaerobic activities was obtained from Wingate test (FI_W) by dividing the lowest power over a five second period by the highest power over a five second period. Additionally, two types of heart rate recovery indices, ΔHR_W for Wingate test and ΔHR_{L1} - ΔHR_{L3} for each line drill test, were identified by subtracting the recovery heart rate from the peak heart rate. Relationships between $VO2_{max}$ and each of the P_{peak}, P_{mean}, T_1 - T_3, FI_W, ΔHR_W, and ΔHR_{L1} - ΔHR_{L3} were examined with Pearson correlation coefficient. Significant relationship with $VO2_{max}$ was observed in P_{mean} ($r = 0.57$; $p \leq 0.05$) but not observed in any of P_{peak} and T_1 - T_3 ($p > 0.05$). These results implied that basketball players with higher $VO2_{max}$ did not tend to have superior outcome (i.e., sprint time) in the field task, while they tended to have higher overall power in the Wingate test. Additionally, no significant relationship to $VO2_{max}$ was observed in any of the fatigue index and heart rate recovery indices ($p > 0.05$). These results suggested that higher $VO2_{max}$ was not necessarily associated with either higher ability to sustain high level of output during the Wingate test or higher cardiodeceleration in the both tests. Although they were not statistically significant and corresponding *p* levels were not reported, the strength of relationship between $VO2_{max}$ and heart rate recovery indices in the line drill tests tended to increase in sequence (r = -0.04, -0.19, and -0.30 for ΔHR_{L1}, ΔHR_{L2}, ΔHR_{L3}, respectively; $p > 0.05$). From this observation, the authors suggested that it would be interesting to assess whether this tendency is enhanced when the bouts of exercise had continued and the nature of exercise becomes closer to actual basketball performance.

In order to determine intensity and physiological demands in female basketball players by positions and competition levels, Rodriguez-Alonso et al. (2003) measured their BLC and HR during games. Fourteen female basketball players, including three guards, seven forwards, and four centers, in the Spanish Olympic team and eleven female players, including three guards, four forwards, and four centers, in a team from the

Spanish national league were asked to participate in this study as volunteer subjects. The Olympic players played in seven international games and two practice games and the national players played in three national games. During each game, all the players were asked to wear a heart rate transmitter and a receiver to record their HR every five seconds. Also, blood sampling for analyzing the BLC were performed at their ear lobes in the first minute of time-outs, changes, and resting periods during each game. Prior to the field tests, their maximum HR (HR_{max}), maximal BLC (BLC_{max}), and HR at lactate threshold (HR_{LT}) were measured in the laboratory. The results showed that mean HR during a game was significantly different between positions (guard, 185 ± 6 bpm; forward, 175 ± 11 bpm; center, 167 ± 12 bpm; $p \leq 0.05$) and between international games and both national and practice games (international, 186 ± 6 bpm; national, 175 ± 13 bpm; practice, 170 ± 11 bpm; $p \leq 0.05$). The mean HR during international, national, and practice games were equivalent to their 94.6 % HR_{max}, 90.8 % HR_{max}, and 89.8 % HR_{max}, respectively, and all the values were above their HR_{LT} (i.e., 89.2 % HR_{max} for the Olympic players and 88.6 % HR_{max} for the national players). The mean BLC in guards was significantly higher than the other positions (guards, 5.7 ± 2.1 mmol/L; forwards, 4.2 ± 2.1 mmol/L; centers, 3.9 ± 2.0 mmol/L; $p \leq 0.05$) and that in practice was significantly lower than the other conditions (international, 5.0 ± 2.3 mmol/L; national, 5.2 ± 2.0 mmol/L; practice, 2.7 ± 1.2 mmol/L; $p \leq 0.05$). The mean BLC during international, national, and practice games were equivalent to their 51.6 % BLC_{max} and 61.9 % BLC_{max}, and 28.1 % BLC_{max}, respectively. The authors concluded that the intensity of female basketball is relatively high and may be altered by competition levels and positions.

In their comprehensive study reviewed in the last section, McInnes et al. (1995) also assessed physiological responses in male basketball players during basketball performance and examined relationships between these responses and their movement patterns. Throughout the official or practice games, each subject's HR was measured by a telemetric heart rate monitor in every 15 seconds and categorized as follows: below 75 % HR_{max}, 75-80 % HR_{max}, 80-85 % HR_{max}, 85-90 % HR_{max}, 90-95 % HR_{max}, above 95 % HR_{max}. Additionally, blood sample was collected to measure the BLC every break including timeouts, substitutions and other resting periods. These measurements were synchronized with time-motion analysis data and arranged on the same time frame. The results revealed that average HR during the live time was 169 ± 9 bpm which was equivalent to 89 ± 2 % HR_{max}, and about 75 % of the live time was spent with HR more than 85 % HR_{max}. The mean BLC through all samples and mean BLC_{max} in all subjects were 6.8 ± 2.8 mmol/L and 8.5 ± 3.1 mmol/L, respectively. There were significant correlations between the BLC and both the percent time spent in high-intensity activities and the mean % HR_{max} for the 5 minutes preceding blood sampling ($r = 0.64$ and $r = 0.45$, respectively; $p \leq 0.05$). No significant difference was found between the percent time spent in high-intensity activities and the mean % HR_{max} for the 5 minutes preceding blood sampling ($p > 0.05$). Based on all results from time-motion and physiological analyses, the authors made several interpretations with respect to physiological and bioenergetic demands of basketball including the following: the physiological requirements for male basketball players are relatively high, as evidenced by the elevated BLC and sustained high HR response despite the relatively low percent of live time spent in high-intensity activities; glycolysis may perform an important role as an energy source in basketball games; and HR may not be adequate as an indicator of exercise intensity during basketball games.

Crisafulli et al. (2002) conducted an innovative study with relatively novel equipment to evaluate biomechanical and physiological indices for quantifying competence of basketball players. Eight male basketball players belonging to a team in an Italian basketball league were involved in this study. After practice in a competition season, each of the players was asked to perform a supra-maximal basketball task including five consecutive running shots after dribbling from center line of the basketball court. A small portable gas analyzer was fitted to the subject's upper body to measure VO2, VCO2 (carbon dioxide production), VE (minute ventilation), RER (respiratory exchange ratio), and HR every five seconds during the test. Oxidative work (J_{oxy}) was estimated by VO2. Also, as an indicator of the lactacid anaerobic capacity, CO2 excess ($CO2_{exc}$) was calculated by the following equation: $CO2_{exc}$ = VCO2 - (resting RER x VO2). At the same time, player's movement was filmed by a video camera at about a 10 Hz sampling frequency to analyze displacement, velocity and acceleration during the tasks, and mechanical work output (J_{mec}) and mean power (P_{mean}) were obtained. Index of mechanical work efficiency (μ_{index}) was then calculated by dividing J_{mec} by J_{oxy} (i.e., $\mu_{index} = J_{mec} / J_{oxy}$). The results of correlation analyses revealed that there were significant and relatively strong positive relationships between μ_{index} and mean velocity ($r = 0.90$; $p \leq 0.01$), acceleration ($r = 0.78$; $p \leq 0.05$), P_{mean} ($r = 0.76$; $p \leq 0.05$), and $CO2_{exc}$ ($r = 0.95$; $p \leq 0.01$). On the other hand, there was no significant relationship between

μ_{index} and mean HR, VE, VO2 and RER ($p > 0.05$). The authors suggested that index of mechanical work efficiency is a good indicator to evaluate basketball players' competence. They also speculated that anaerobic capacity is one of the most important traits required in basketball players to achieve high level of outputs including speed, acceleration and mechanical power.

As discussed above, some research groups have assessed bioenergetic variables throughout basketball games and/or alternative drills. Additionally, two studies have tried to examine the relationships between bioenergetic traits of players and their performance outcomes by integrating bioenergetic analysis with time-motion or kinematic analysis (Crisafulli et al., 2002; McInnes et al., 1995). These studies may provide more precise and rational information about the bioenergetics of basketball than conventional profile analysis studies. In spite of the potential benefits of these approaches, there seems to be several limitations in the bioenergetic assessment. One limitation may be that no study has succeeded to quantify aerobic metabolism during actual basketball performances. For instance, McInnes et al. (1995) measured players' heart rate during games, but the authors hesitated to estimate oxygen metabolism from these results because the heart rate data may not provide a true reflection of oxygen uptake during intermittent exercises (Balsom, Seger, Sjodin & Ekblom, 1992). Although Crisafulli et al. (2002) actually quantified subjects' oxygen uptake using a portable gas analyzer, they did not collect data in actual basketball games but in basketball drills. To fully describe the bioenergetic traits of basketball, both aerobic and anaerobic metabolism should be taken into account in the real basketball performances.

Summary

Sport-specific traits of basketball and its physiological bioenergetic demands have been conventionally discussed based only on descriptive and indirect observations. However, implications for better understanding the bioenergetics of this sport have been still lacking from these types of studies. To gain more clear and rational insights, several research groups have started direct measurements of variables in actual basketball performance with time-motion analysis, bioenergetic analysis, and combination of them. In spite of great potential of these approaches, the findings have been still limited and further attempts seem to be needed. Examining velocity is considered one possible way to objectively determine the intensity of actual basketball performance and to assess its bioenergetic demands. As well, examining aerobic metabolism (i.e., oxygen consumption) is necessary to fully describe the bioenergetics of this sport. Tables 1 to 3 provide a summary of the studies reviewed in this literature.

Table 1

Summary of Reviewed Articles 1

Author (Year)	Topic	Purpose	Subjects	Measurement	Results
Latin et al. (1994)	Physical and physiological profiles	To describe physical profiles of top collegiate male BB players	437 male BB players	H, BM, PBF, VJ, 1-RM BP, 1-RM SQ, 40-yd dash, T-test, 1 mile run, etc.	Several significant differences between positions and teams ($p \leq 0.01$)
Berg et al. (1995)	Physical and physiological profiles	To compare physical profiles between male BB and football players	437 male BB and 880 football players	H, BM, PBF, VJ, 40-yd dash, 1-RM BP, 1-RM SQ	Several significant difference between two groups ($p \leq 0.01$)
Gillam (1985)	Physical and physiological profiles	To compare physical profiles between male BB players and college students	13 male BB players and 14 students	H, BM, FFM, PBF, 1-RM BP, 1-RM SQ, 15-yd and 50-yd dash, VJ, S&R, etc.	Several significant difference between two groups ($p \leq 0.05$)
LaMonte et al. (1999)	Physical and physiological profiles	To depict physical and performance traits of female BB players by positions	46 female BB players	H, BM, FFM, PBF, VJ, P_{mean}, P_{peak}, etc.	Several significant differences between positions ($p \leq 0.05$)
Hunter et al. (1993)	Change of profiles across BB seasons	To examine changes of physical profiles in collegiate male BB players during BB career	42 male BB players	BM, PBF, LBM, $VO2_{max}$, 1-RM BP, 1-RM SQ, S&R, VJ, P_{mean}, P_{peak}	Several significant differences between adjacent 2 seasons ($p \leq 0.01$ and 0.05); no significant different PBF, $VO2_{max}$ and S&R

Note. BB: basketball, BM: body mass, BP: bench press, FFM: fat free mass, H: height, LBM: lean body mass, PBF: percent body fat, P_{mean}: mean power, P_{peak}: peak power, RM: repetition maximum, SQ: squat, S&R: set-and-reach test, VJ: vertical jump, $VO2_{max}$: maximal oxygen consumption.

Table 2

Summary of Reviewed Articles 2

Author (Year)	Topic	Purpose	Subjects	Measurement	Results
Tavino et al. (1995)	Change of profiles within BB season	To evaluate the effects of BB season on fitness and body composition	9 male BB players	BM, PBF, $VO2_{max}$, AC	Several significant differences between pre and post BB seasons ($p \leq 0.05$)
Hoffman et al. (1991)	Change of profiles within BB season	To examine if BB players can sustain physical conditions during BB season	9 male BB players	BM, SF, thigh girth, 1-RM BP, 1-RM SQ, 27m sprint, 1.5 mile run, T-test, VJ	Significant reduction of 27 m sprint time ($p \leq 0.05$) in post BB season
Caterisano et al. (1997)	Change of profiles within BB season	To assess the effects of playing time in BB games on the changes of profiles	17 male BB players (9 starters and 8 reserves)	BM, PBF, $VO2_{max}$, 1-RM BP, 1-RM LP, etc.	Significant decrease of $VO2_{max}$ in reserves, 1-RM LP in starters, 1-RM BP in both in post BB season ($p \leq 0.05$)
Hoffman et al. (1996)	Relationship between profiles and performance outcomes	To examine if fitness testing scores predict playing time in season BB games	29 male BB players	PT, 1-RM BP, 1-RM SQ, T-test, 27 m sprint, VJ, 1.5 mile run	Significant relationships between PT and 1-RM SQ, 27 m sprint, VJ, and 1.5 mile run ($p \leq 0.05$) in two or more seasons
McInnes et al. (1995)	Bioenergetic demands of BB	To describe physiological traits of and movement patterns in BB games	8 male BB players	HR, BLC, TMA (duration and frequency of defined movements)	Significant relationships between BLC and % time for high-intensity activities and mean $\%HR_{max}$ ($p \leq 0.05$)

Note. AC: anaerobic capacity by step test, BLC: blood lactate concentration, HR: heart rate, HR_{max}: maximum HR, LP: leg press, PT: playing time, SF: skinfold, TMA: time-motion analysis.

Table 3

Summary of Reviewed Articles 3

Author (Year)	Topic	Purpose	Subjects	Measurement	Results
Taylor (2003)	Traits of movements in BB games	To quantify traits of movements for developing sound training programs	1 male BB player (in 4 games)	TMA (duration and frequency of defined movements)	134.8 ± 32.4 of high intensity bouts per game, 150.3 ± 40.6 of sub-maximal intensity bouts per game, etc.
Hoffman et al. (1999)	Bioenergetic demands of BB	To examine relationships between aerobic capacity and fatigue and HR recovery	20 male BB players	$VO2_{max}$, P_{mean}, P_{peak}, sprint time, fatigue index, HR recovery indices	Significant relationship between $VO2_{max}$ and P_{mean} ($p \leq 0.05$)
Rodriguez-Alonso et al. (2003)	Bioenergetic demands of BB	To assess bioenergetic demands in female BB players by positions and competition levels	14 female BB players	HR_{max}, BLC_{max}, HR_{LT}, HR, BLC	Significant differences on HR and BLC between positions and between competition levels ($p \leq 0.05$)
Crisafulli et al. (2002)	Bioenergetic demands of BB	To evaluate biomechanical and physiological indices for quantifying competence of BB players	8 male BB players	VO2, VCO2, VE, RER, HR, $CO2_{exe}$, J_{oxy}, J_{mec}, P_{mean}, μ_{index}, etc.	Significant positive relationships between μ_{index} and both P_{mean} and $CO2_{exc}$ ($p \leq 0.01$ and 0.05); no significant relationships between μ_{index} and any of HR, VE, VO2 and RER

Note. BLC_{max}: maximum blood lactate concentration, $CO2_{exc}$: CO2 excess, HR_{LT}: HR at lactate threshold, J_{mec}: mechanical work, J_{oxy}: oxidative work, RER: respiratory exchange ratio, VE: minute ventilation, VO2: oxygen consumption, μ_{index}: index of mechanical work efficiency.

Chapter 4 – Methods

Subjects

Six female and six male basketball players of the University of Nebraska at Omaha (UNO) men's and women's basketball teams volunteered to participate in this study (see Table 4). Most of these subjects were starters in the 2004-2005 season. Prior to the commencement of any tests, all the subjects, as well as other five female and six male players who performed team scrimmages with the subjects, were examined with a standardized medical history form to determine if they are free from any major cardiovascular risks and musculoskeletal problems. At the same time, they were fully informed of the nature of the study and asked to sign an informed consent form in accordance with the guidelines of the Institutional Review Board at the University of Nebraska Medical Center.

Experimental Design

Within three weeks after the completion of the 2004-2005 season, both the female and male teams played regular basketball in six team scrimmages scheduled in two days (i.e., three scrimmages per day), respectively. Each scrimmage was performed in conformity with the NCAA regulation except for the format and duration. Specifically, the scrimmage was designed to mimic one-half of an official game and to consist of four playing periods (PPs) of about five minutes each (i.e., about 20 minutes play time) and alternate resting periods (RPs) of about one minute each (i.e., about 3 minutes rest time). The scrimmage was administered in the same way as actual games with cooperation of all players, coaches, referees, and scorers to simulate true game conditions.

Table 4

Profile of Subjects

ID	Position	Age, yr	Height, cm	Weight, kg	Play Time, min[a]
		Female (n = 6)			
S1	Guard	21	166.4	68.3	308
S2	Forward	20	180.3	75.4	812
S3	Guard	19	172.7	59.9	278
S4	Forward	22	180.3	68.1	852
S5	Guard	19	161.3	60.8	953
S6	Center	19	184.2	69.0	519
	Mean ± SD	20.0 ± 1.2	174.2 ± 8.2	66.9 ± 5.2	620.3 ± 266.5
		Male (n = 6)			
S7	Center	21	207.0	111.2	63
S8	Center	21	200.7	114.4	552
S9	Forward	19	188.0	83.1	433
S10	Forward	21	193.0	91.7	388
S11	Guard	22	172.7	72.2	385
S12	Guard	21	193.0	78.5	787
	Mean ± SD	20.8 ± 0.9	192.4 ± 10.7	91.9 ± 15.9	434.7 ± 216.3

Note. [a]Total playing time in all official games during the 2004-2005 season.

In each scrimmage, a single subject was assigned for data collection in advance. The subject played basketball while wearing portable measurement systems throughout the scrimmage. Within one to three days before the scrimmage, the subject also performed preliminary tests. All the field testing (i.e., scrimmages) were performed at the UNO Sapp Field House or the HPER Building and all the preliminary testing were performed at the UNO HPER Exercise Physiology Laboratory.

Measurement

<u>Preliminary Testing</u>

To determine height, body weight, body fatness, and $VO2_{max}$, as well as to familiarize the subject with wearing a portable metabolic measurement system employed in the field testing, the preliminary testing was performed. Prior to the preliminary testing, the subject was asked to avoid having high intensity and/or volume of physical activities within 24 hours before the participation.

Anthropometric Measurement

After the confirmation of age, the subject's height and body weight was measured by a general combination scale (Detecto Medic; Detecto Scales, Inc., Brooklyn, NY). Then, the subject's skinfold thickness was measured at three sites with a skinfold caliper (Vital Signs Model 68875; Country Technology, Inc., Gays Mills, WI). Specifically, right triceps, suprailium, and thigh were selected for female subjects and right chest, abdomen, and thigh were selected for male subjects. Each site was located and measured with a specific standardized procedure (American College of Sports Medicine, 2000) until two scores within 1.0 mm of one another were obtained. These two scores were averaged and the subject's body density was estimated from the sum of three averaged skinfold thickness scores by using the Jackson-Pollock (JP) and Jackson-Pollock-Ward (JPW) generalized equations (Jackson and Pollock, 1978; Jackson, Pollock & Ward, 1980). Then, percent body fat was calculated from the body density by using the Siri equation (Siri, 1956). These two equations have a SEE (standard error of estimation) for body fat values within $\pm$ 3.5 % (Ross & Jackson, 1990).

Treadmill Graded Exercise Test (GXT)

After the anthropometric measurement, the subject engaged in a GXT protocol on a treadmill (SensorMedics Model 2000; SensorMedics Corporation, Yorba Linda, CA). Prior to the protocol, the subject was asked to put a heart rate monitor (Polar S610i Heart Rate Monitor; Polar Electro Oy, Kempele, Finland) on the wrist and a heart rate transmitter (Polar T61 Coded Transmitter; Polar Electro Oy) on the chest underneath a shirt. These monitor and transmitter were synchronized by the investigator to monitor HR throughout the protocol. After that, the investigator fitted a portable metabolic measurement system (MedGraphics VO2000 portable metabolic measurement system; Medical Graphics Corp., St. Paul, MN) and its accessory components on the subject's body using a standardized procedure to determine VO2 from the analysis of expired air (see Figure 1).

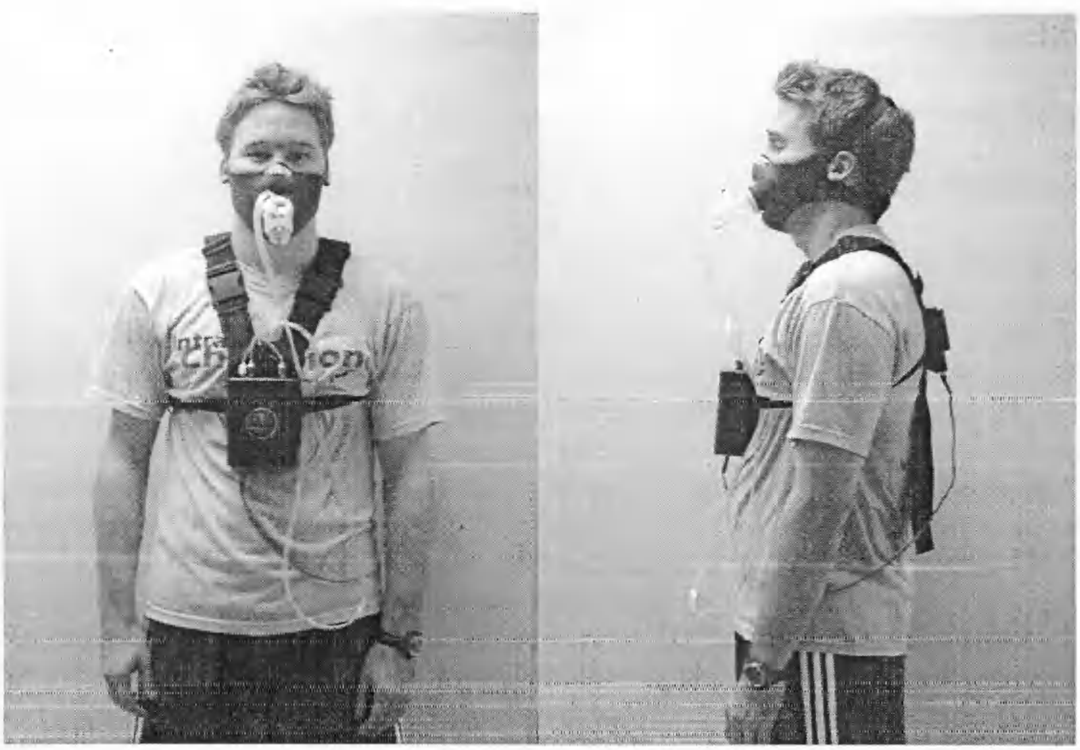

Figure 1. Portable metabolic measurement system.

This portable metabolic measurement system mainly consists of a main unit, a face mask (PreVent Mask; Medical Graphics Corp., St. Paul, MN) with a pneumotach (PreVent Exercise Pneumotach; Medical Graphics Corp., St. Paul, MN), an umbilical cord connecting the pneumotach to the main unit, a battery unit, and two serial cables connecting the main unit to the battery unit and to an external computer (Gateway E-4200 Series; Gateway, Inc., Irvine, CA) which contains a control software (BreezeSuite 6.1B; Medical Graphics Corp., St. Paul, MN). The O2 analyzer in the main unit was calibrated using an auto-calibration function of the system. The manufacturer reported the accuracy of O2 analyzer with the auto-calibration function as within ± 0.1 % (Medical Graphics Corp., 2004). Additionally, Byard and Dengel (2002) reported that VO2 values obtained by the system were strongly correlated to those measured by a conventional metabolic cart (MedGraphics CPX/D metabolic measurement system; Medical Graphics Corp., St. Paul, MN) ($r = 0.981, p \leq 0.0001$). Up to180 consecutive data sets were stored into a memory in the main unit with a sampling frequency of 0.05 Hz (i.e., VO2 was measured for up to 60 minutes). Before starting the protocol, the main unit was activated and disconnected from the computer. After the completion of the protocol, the main unit was reconnected to be deactivated, as well as to download the stored data to the external computer.

The GXT protocol was started at a speed of 3 mph with 0 % grade, and then, either speed or grade was increased by stages. The duration and increment of speed or grade were determined for each stage according to the subject's condition. To monitor the subject's condition, HR was checked throughout the protocol, as well as RPE was measured using a RPE scale chart (Young Enterprises, Inc., Lansing, KS) at the end of each stage. The protocol was continued until volitional termination due to fatigue. Immediately after the termination, the speed and grade of the treadmill were changed reduced to 3 mph and 0 %, respectively, and the subject kept walking until HR dropped below 120. Three minutes after the termination of the test, a blood sample was drawn from a finger of the subject using a minimally invasive lancet (Accu-Chek Safe-T-Pro Lancets; Roche Diagnostics, Mannheim, Germany) and a glass capillary tube (Cholestech LDX Capillary Tubes; Cholestech Corporation, Hayward, CA). Then, the blood sample was put on a test strip (BM-Lactate; Roche Diagnostics, Mannheim, Germany) to measure BLC using a portable lactate analyzer (Accusport; Boeringer Mannheim, Castle Hill, Australia). According to Pinnington and Dawson (2001), measurement with this analyzer was highly correlated to results from venipuncture and standard blood assay technique ($r = 0.853$; $p \leq 0.05$) and also demonstrated strong test-retest reliability ($r = 0.995$; $p \leq 0.05$). The peak VO2 value during the protocol was regarded as the subject's $VO2_{max}$ when three of the following four criteria were met: a) attainment of the RPE greater than or equal to 19, b) attainment of the HR within 10 bpm of age predicted maximal heart rate (i.e., 220 - age), c) attainment of the BLC greater than or equal to 8.0 mmol/L, and d) attainment of the VO2 increment (ΔVO2) within 2.0 ml/kg/min.

Field Testing

To measure several variables regarding the subject's bioenergetics in actual basketball performance, the field testing (i.e., team scrimmage) was performed. Prior to the scrimmage, the subject assigned, as well as other players, were strongly encouraged by the coaches and investigators to play with similar intensity as actual games. Additionally, the game intensity was also tried to be facilitated with the presence of the coaches and use of referees and scores during the scrimmage.

Measurement during Scrimmage

After performing moderate warm-up for 10 to 15 minutes (for the first scrimmage of the day) or about 10 minutes after the completion of the previous scrimmage (for the second and third scrimmages of the day), the heart rate transmitter and monitor, as well as the portable metabolic measurement system, were fitted to the subject's body and activated simultaneously. Throughout the scrimmage, the HR and VO2 were measured by these devices with a sampling frequency of 0.05 Hz (i.e., every 20-second interval). At the onset of the scrimmage, elapsed time from the activation of the portable devices was recorded for subsequent data analysis (i.e., to synchronize HR and VO2 data with the video data afterwards). Additionally, the BLC and RPE were measured right after the beginning of each RP and immediately after the completion of the scrimmage. The RPE scale chart was displayed on a cart where lactate analysis was done.

Videotaping for Time-Motion Analysis

During the PPs in the scrimmage, the subject was videotaped by a digital video camcorder (ZR20; Canon U.S.A., Inc., Lake Success, NY) and a mini DV tape (FUJI DVM-60ME; Fuji Photo Film Co., Ltd., Kanagawa, Japan) for a time-motion analysis. Specifically, the camcorder was placed on the courtside using a tripod and the subject's movements, especially lower-extremity movements, were captured throughout the scrimmage. The obtained video image was analyzed using a mini DV player

(HR-DVS3U; Victor Company of Japan, Limited, Kanagawa, Japan). Table 5 demonstrates criteria to categorize the subject's movements (Razeghi & Batt, 2000; Merriam-Webster Online Dictionary, 2005). From the beginning of the scrimmage, a dominant movement for every one-second interval was classified as walk, run, jump, or stand by referring to the criteria and coded into a spreadsheet. For instance, if consecutive shuffling (lateral movements) with single and double support phases and without floating phases dominated a given one-second interval, this interval was coded as walk. Through this process, frequency counts, total duration, and mean duration (per event) of respective intermittent movements on the Table 5 were determined. Furthermore, PAM, the percent of duration for active movements including runs and jumps, was calculated from the coded data sets for every 20-second interval.

Data Analysis

Data are presented as means and standard deviations (M ± SD). Independent *t*-tests and two-way (gender x playing period) ANOVAs (analyses of variances) for repeated measures with Tukey's post-hoc test were employed to compare mean values between groups (i.e., females and males) and among four different PPs. Pearson correlation coefficient (Pearson *r*) was used to assess relationships between variables. All statistical analyses were performed using the SPSS Version 13.0 (SPSS Inc., Chicago, IL). Significance level was set at $\alpha = 0.05$.

Table 5

Criteria for Time-Motion Analysis

Movements	Criteria
Stand	The subject stands on the court without any steps
Walk	The subject locomotes on the court multidirectionally or pivots with consecutive movements including single and double support phases and without floating phases
Run	The subject locomotes on the court multidirectionally with consecutive movements including single support and float phases and without double support phases
Jump	The subject springs into the air using one or two leg take-off

Chapter 5 – Results

Preliminary Testing

All the twelve subjects completed the preliminary testing. Table 6 summarizes the results of the preliminary testing. The male subjects were significantly heavier, taller, and leaner than female subjects (37.4, 10.4 and -51.5 %; t = -3.32, -3.01 and 1.37; $p \leq 0.05$). Since the results of the treadmill GXT for two male subjects did not meet the criteria explained in the previous chapter, the $VO2_{max}$ are reported only for six female and four male subjects (see Table 7).

Table 6

Results of Preliminary Testing

Variable	Female (n = 6) Mean ± SD (Range)	Male (n = 6) Mean ± SD (Range)
Age, yr	20.0 ± 1.2 (19 - 22)	20.8 ± 0.9 (19 - 22)
Body Weight, kg*	66.9 ± 5.2 (59.9 - 75.4)	91.9 ± 15.9 (72.2 - 114.4)
Height, cm*	174.2 ± 8.2 (161.3 -184.2)	192.4 ± 10.7 (172.7 - 207.0)
Percent Body Fat, %*	19.8 ± 4.1 (13.3 - 26.6)	9.6 ± 5.4 (4.6 - 20.5)
$VO2_{max}$, ml/kg/min	50.3 ± 5.4 (43.8 - 59.9)	57.5 ± 7.1[a] (48.4 - 67.3)
$VO2_{max}$, ml/min*	3360.0 ± 388.5 (2760.0 - 4080.0)	5467.5 ± 449.5[a] (4750.0 - 5990.0)
$VO2_{max}$, ml/kg$^{0.67}$/min*	201.1 ± 21.1 (177.8 - 241.2)	257.7 ± 20.6[a] (231.4 - 289.3)

Note. *Significant difference between the groups ($p \leq 0.05$). [a]Sample size (n) = 4.

Table 7

Individual Results of Treadmill GXT

ID	Peak RPE	Peak HR, Bpm	BLC, Mmol/L	ΔVO2, ml/kg/min	$VO2_{max}$, ml/kg/min
		Female (n = 6)			
S1	19	199	11.5	3.0[a]	47.7
S2	19	190	7.5[a]	1.4	43.8
S3	19	204	8.5	0.7	46.1
S4	20	168[a]	12.2	1.9	59.9
S5	20	199	6.5[a]	0.3	54.2
S6	20	184[a]	8.5	1.8	50.1
Mean ± SD	19.5 ± 0.5	190.7 ± 12.1	9.1 ± 2.1	1.5 ± 0.9	50.3 ± 5.4
		Male (n = 6)			
S7	20	192	11.7	1.0	53.9
S8	19	182[a]	9.5	0.8	48.4
S9	20	195	9.5	6.0[a]	67.3
S10	19	185[a]	7.4[a]	0.7	(43.5)[b]
S11	19	185[a]	4.8[a]	1.1	(49.3)[b]
S12	20	200	9.3	1.6	60.5
Mean ± SD	19.5 ± 0.5	189.8 ± 6.4	8.7 ± 2.1	1.9 ± 1.9	57.5 ± 7.1[c]

Note. [a]Scores did not meet the criterion for determining $VO2_{max}$. [b]Scores were not regarded as $VO2_{max}$ since only two or less criterion were met. [c]Sample size (n) = 4.

The mean $VO2_{max}$ for the female and male groups were 50.3 ± 5.4 and 57.5 ± 7.1 ml/kg/min, respectively. The male group demonstrated significantly greater $VO2_{max}$ than the female group when represented in ml/min and in ml/kg$^{0.67}$/min (62.7 and 28.1 %; t = -6.75 and -3.73; $p \leq 0.05$) while not significantly greater when represented in ml/kg/min (14.3 %; $p > 0.05$). However, when examining all data regardless of the groups (n = 10), a significant relationship was found between $VO2_{max}$ in ml/min and body weight ($r = 0.866$; $p \leq 0.05$), indicating that $VO2_{max}$ with this unit was strongly dependent on body weight. Also, r statistic between $VO2_{max}$ in ml/kg$^{0.67}$/min and body weight was $r = 0.496$ ($p > 0.05$), suggesting that $VO2_{max}$ with this unit was fairly dependent on body weight. In contrast, the r between $VO2_{max}$ in ml/kg/min and body weight was closed to null ($r = 0.058$; $p > 0.05$), suggesting that $VO2_{max}$ with linear-relative expression (i.e., ml/kg/min) was nearly independent of body weight.

Field Testing

Measurement during Scrimmage

All the twelve subjects successfully played basketball in the team scrimmages for data collection. However, since a strap for the heart rate transmitter slackened during play, the HR values were not collected for two subjects (S1 and S11). Additionally, due to lack of sufficient volume of blood sample, the BLC value was not read by the portable lactate analyzer only for one PP in one scrimmage (S6). Figure 2 depicts the data collection during the scrimmage.

Figure 2. Data collection during scrimmage. The left picture depicted measurement by the portable metabolic measurement system during a playing period and the right picture depicted a blood sampling during a resting period.

Representative VO2 and HR data from one subject (S9) are presented in Figure 3. This graph visually demonstrates that the VO2 and HR values rose and dropped rapidly at the onset and right after the completion of each PP, and that they fluctuated considerably during the respective PPs.

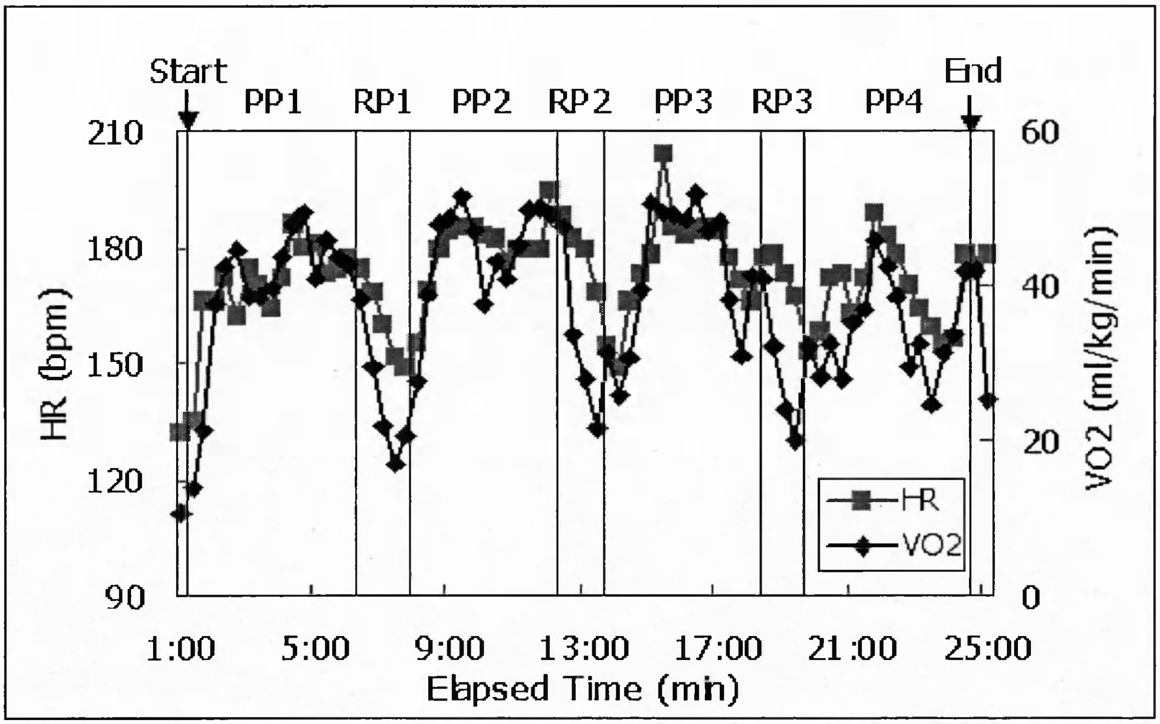

Figure 3. Representative VO2 and HR in scrimmage of one player. The diamond and cube indicate VO2 and HR values in every 20-second interval, respectively. The PP and RP denote playing and resting periods, respectively.

Table 8 summarizes the results of the measurement during the scrimmage. The play and rest time were shorter and longer for about 1.4 minutes in the females and 1.9 minutes for the males than those originally designed. This discrepancy was mainly due to variations in the time to perform BLC measurement.

Table 8

Results of Field Testing (Measurement during Scrimmage)

Variable	Female (n = 6) Mean ± SD (Range)	Male (n = 6) Mean ± SD (Range)
Play time, min	18.61 ± 0.24 (18.33 - 19.00)	18.09 ± 1.09 (16.22 - 19.58)
Rest time, min	4.38 ± 0.24 (4.00 - 4.67)	4.93 ± 1.09 (3.42 - 6.78)
VO2 during play, ml/kg/min	33.4 ± 3.6 (28.5 - 39.0)	37.0 ± 2.4 (33.3 - 40.5)
%$VO2_{max}$ during play, %	66.7 ± 6.9 (60.9 - 81.7)	64.8 ± 6.0[a] (57.7 - 72.4)
Energy expenditure rate during play, kcal/min*	11.2 ± 1.4 (9.0 - 13.3)	16.9 ± 2.9 (13.2 - 21.7)
HR during play, bpm	168.7 ± 9.9[b] (152.3 - 179.1)	169.3 ± 4.0[b] (162.3 - 174.5)
VO2 during rest, ml/kg/min	21.2 ± 1.9 (19.2 - 25.2)	22.8 ± 3.0 (18.9 - 26.9)
%$VO2_{max}$ during rest, %	42.6 ± 5.6 (35.1 - 52.8)	41.1 ± 8.9[a] (31.3 - 55.6)
Energy expenditure rate during rest, kcal/min*	7.1 ± 0.8 (6.1 - 8.6)	10.6 ± 2.7 (7.4 - 15.4)
HR during rest, bpm	152.5 ± 10.3[b] (134.4 - 164.0)	150.4 ± 10.2[b] (135.5 - 165.9)
BLC during play, mmol/L	3.2 ± 0.8 (2.5 - 4.4)	4.1 ± 1.2 (3.1 - 6.8)
RPE during play	14.3 ± 1.8 (12.3 - 17.5)	13.7 ± 0.9 (12.5 - 15.0)
Total energy expenditure, kcal*	239.0 ± 29.5 (193.0 - 285.9)	356.5 ± 60.0 (275.4 - 430.2)

Note. *Significant difference between the groups ($p \leq 0.05$). [a]Sample size (n) = 4. [b]Sample size (n) = 5.

The mean VO2 during play were 33.4 ± 3.6 ml/kg/min for the female group and 37.0 ± 2.4 ml/kg/min for the male group, respectively. The male group revealed 10.8 % greater mean VO2 than the female group while this difference was not significant ($p > 0.05$). The associated %$VO2_{max}$ values were 66.7 ± 6.9 % for the female group and 64.8

$\pm$ 6.0 % for the male group; the value of the females was 2.9 % greater than that of the males ($p > 0.05$). The mean VO2 values during play are equivalent to 9.5 and 10.6 METs, as well as the VO2 for horizontal running at 149.5 and 167.5 m/min (5.6 and 6.2 mph) when using an equation by the American College of Sports Medicine (2000). The mean energy expenditure rates during play, which were estimated from the VO2 using 1 L O2 = 5 kcal, were significantly (50.9 %) greater in the male group than in the female group (16.9 $\pm$ 2.9 and 11.2 $\pm$ 1.4 kcal/min; t = -3.97; $p \leq 0.05$). The mean VO2 values during rest and associated $\%VO2_{max}$ values were 21.2 $\pm$ 1.9 ml/kg/min (6.1 METs) and 42.6 $\pm$ 5.6 % for the females and 22.8 $\pm$ 3.0 ml/kg/min (6.5 METs) and 41.1 $\pm$ 8.9 % for the males. The males demonstrated 7.5 % higher VO2 and 3.5 % lower $\%VO2_{max}$ values than the females during rest ($p > 0.05$, respectively). The mean energy expenditure rates during rest were significantly (49.3 %) greater in the male group than in the female group (10.6 $\pm$ 2.7 and 7.1 $\pm$ 0.8 kcal/min; t = -2.73; $p \leq 0.05$).

The male and female groups demonstrated similar mean HR during play (168.7 $\pm$ 9.9 and 169.3 $\pm$ 4.0 bpm; $p > 0.05$), as well as during rest (152.5 $\pm$ 10.3 and 150.4 $\pm$ 10.2; $p > 0.05$). The mean BLC during play was 28.1 % greater in the male group than in the female group, but not significantly different (4.1 $\pm$ 1.2 and 3.2 $\pm$ 0.8 mmol/L; $p > 0.05$). The mean RPE during play was slightly (4.4 %) greater in the female group than in the male group (14.3 $\pm$ 1.8 and 13.7 $\pm$ 0.9; $p > 0.05$). Through the entire scrimmage including both play and rest time, the male subjects expended significantly (49.2 %) greater energy than the female subjects (356.5 $\pm$ 60.0 and 239.0 $\pm$ 29.5 kcal; t = -3.929; $p \leq 0.05$).

The mean HR scores for the second and third PPs were significantly higher than that for the first PP (3.7 and 3.5 %, respectively; F = 5.45; $p \leq 0.05$) (see Figure 4). The mean RPE scores for the second, third, and fourth PPs were significantly higher than that for the first PP (15.7, 18.2 and 28.1 %, respectively; F = 20.32; $p \leq 0.05$) (see Figure 4). In contrast, the mean VO2 and BLC values were not significantly different among the four different PPs in the scrimmage ($p > 0.05$). Additionally, neither between-group main effects nor interactions were found on any of the above variables (i.e., VO2, HR, BLC, and RPE) by the two-way ANOVAs ($p > 0.05$).

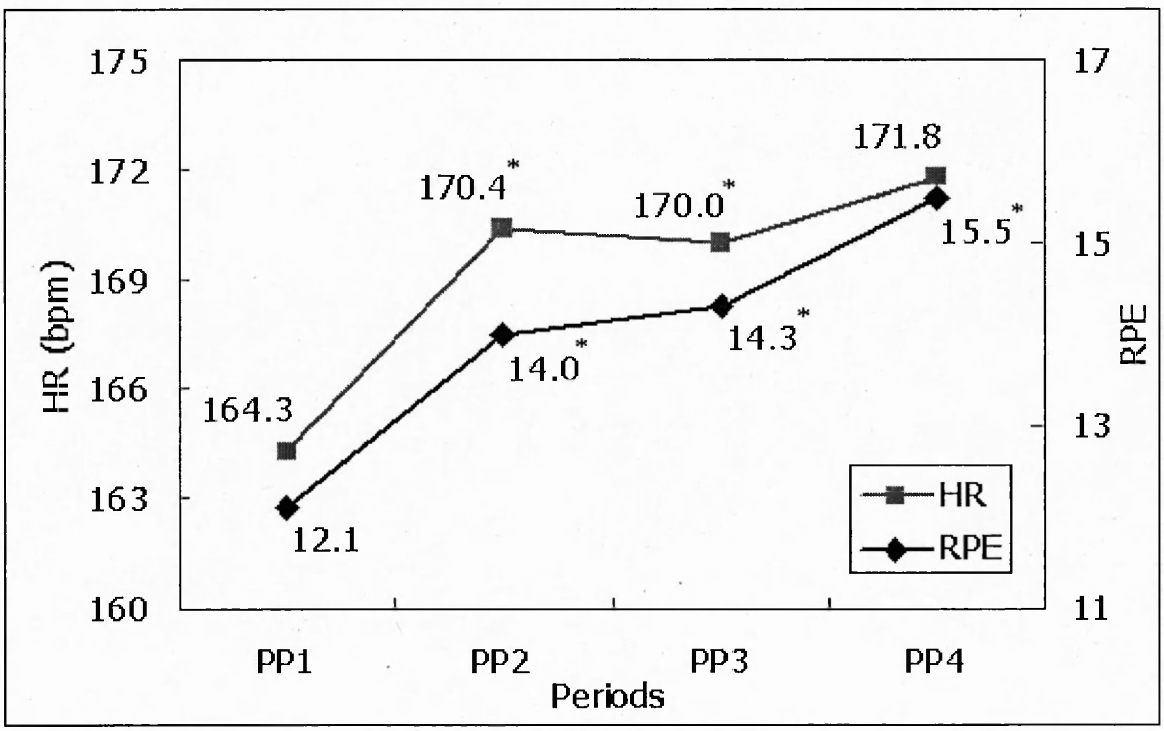

Figure 4. Change of HR and RPE across playing periods in scrimmage. The cube and diamond indicate mean HR (n = 10) and mean RPE (n = 12) values for each period of play. Asterisk (*) indicates significantly larger score (i.e., marginal mean) from that in the first playing period (PP1) ($p \leq 0.05$).

Time-Motion Analysis

In the video data filmed, a dominant movement for every one-second interval was classified as walk, run, jump, or stand, and frequency counts, total duration, and mean duration (per event) of the respective intermittent movements were determined. The results of the time-motion analysis during play time in scrimmages are summarized in Tables 9 to 11. There were no significant differences between the two groups in any variables regarding frequency and duration of the movements ($p > 0.05$), indicating that the female and male groups demonstrated similar pattern of movements during play. Specifically, the mean of frequency counts for the female group was 240.3 ± 18.1 events while that for the male group was 223.7 ± 25.6 events.

Table 9

Results of Field Testing (Frequency of Movements)

Type of movements During play	Female (n = 6) Mean ± SD (Range)	Male (n = 6) Mean ± SD (Range)
Stand, events	23.2 ± 12.1 (8 - 44)	22.8 ± 5.4 (15 - 28)
Walk, events	112.0 ± 4.1 (107 - 119)	105.3 ± 10.9 (91 - 123)
Run, events	89.3 ± 8.8 (77 - 97)	78.2 ± 13.5 (57 - 98)
Jump, events	15.8 ± 5.2 (8 - 22)	17.3 ± 7.6 (10 - 31)
Active[a], events	105.2 ± 8.9 (91 - 117)	95.5 ± 12.0 (81 - 113)
Total, events	240.3 ± 18.1 (224 - 277)	223.7 ± 25.6 (187 - 264)

Note. [a]Active movements include run and jump.

Table 10

Results of Field Testing (Duration of Movements)

Type of movements During play	Female (n = 6) Mean ± SD (Range)	Male (n = 6) Mean ± SD (Range)
Stand, min	1.63 ± 0.78 (0.63 - 3.03)	1.68 ± 0.56 (1.02 - 2.50)
Walk, min	10.56 ± 0.27 (10.20 - 11.03)	10.31 ± 0.96 (8.60 - 11.48)
Run, min	6.16 ± 0.65 (5.15 - 7.25)	5.81 ± 0.74 (4.60 - 6.83)
Jump, min	0.26 ± 0.09 (0.13 - 0.37)	0.28 ± 0.13 (0.17 - 0.52)
Active[a], min	6.43 ± 0.64 (5.38 - 7.43)	6.10 ± 0.68 (5.12 - 7.08)
Total, min	18.62 ± 0.24 (18.33 - 19.00)	18.09 ± 1.09 (16.22 - 19.58)

Note. [a]Active movements include run and jump.

Table 11

Results of Field Testing (Mean Duration of Movements)

Type of movements During play	Female (n = 6) Mean ± SD (Range)	Male (n = 6) Mean ± SD (Range)
Stand, sec/event	4.5 ± 1.2 (2.8 - 6.1)	4.7 ± 2.2 (3.1 - 9.3)
Walk, sec/event	5.7 ± 0.2 (5.3 - 5.9)	6.0 ± 1.0 (4.7 - 7.6)
Run, sec/event	4.2 ± 0.3 (3.7 - 4.7)	4.5 ± 0.3 (4.2 - 4.9)
Jump, sec/event	1.0 ± 0.0 (1.0 - 1.0)	1.0 ± 0.0 (1.0 - 1.0)

The percent of frequency for respective movements was 46.8 and 47.2 % (female and male groups, respectively) for walk, 37.3 and 34.9 % for run, 9.4 and 10.2 % for stand, and 6.6 and 7.8 % for jump. Similarly, the percent of duration for respective movements was 56.7 and 56.9 % for walk, 33.1 and 32.1 % for run, 8.7 and 9.4 % for stand, and 1.4 and 1.6 % for jump. Additionally, the percent of duration for active movements (PAM) was 34.5 and 33.7 % for the female and male groups, respectively. When examining all subjects together (n =12), 34.1 % of time was spent performing active movements including run and jump; while 56.9 % of time was used to walk and 9.0 % was to stand. The mean duration per each bout was 5.7 and 6.0 seconds (female and male groups, respectively) for walk, 4.2 and 4.5 seconds for run, 4.5 and 4.7 seconds for stand, and 1.0 second for jump. The mean PAM was not significantly different among the four different PPs ($p > 0.05$). Also, neither between-group main effect nor interaction was found on PAM ($p > 0.05$).

Correlational Analysis

Significant relationships were found between the VO2 and HR values for every 20-second interval during play in the females and males ($r = 0.283$ and 0.811; $p \leq 0.05$). The associated common variances between these variables were 8.0 % and 65.8 %, respectively. There were also small but significant relationships between the PAM and VO2 values for every 20-second interval during play in both groups ($r = 0.281$ and 0.283; $p \leq 0.05$). In both groups, only about 8 % of variance in the percent of active movements (i.e., PAM) was explained by the VO2 values. Only the male group revealed a significant relationship between the PAM and HR values for every 20-second interval during play, but the association was weak ($r = 0.145$; $p \leq 0.05$).

The mean VO2 and HR values for each PP were also significantly correlated with each other in the male group ($r = 0.782$; $p \leq 0.05$) but not in the female group, as well as when examining all subjects together ($p > 0.05$). There were significant relationships between the mean PAM and VO2 values for each PP in the male group, as well as when examining all subjects together ($r = 0.491$ and 0.342; $p \leq 0.05$); while no significant relationship was found in the female group although the p level indicated a trend ($r = 0.382$; $p = 0.066$). The mean PAM and HR values for each PP were positively correlated in the male group ($r = 0.552$; $p \leq 0.05$) and negatively correlated in the female group ($r = -0.469$; $p \leq 0.05$) while no significant relationship was found when examining all subjects together ($r = -0.143$; $p > 0.05$). There was no significant relationship between the mean PAM values and BLC values for each PP in both groups, as well as when examining all subjects together ($p > 0.05$). The RPE values for each PP was not significantly correlated to any of the mean VO2, HR, PAM values and the BLC values for each PP ($p > 0.05$). Interestingly, when examining all subjects together, the mean BLC during play was significantly related to the body weight ($r = 0.632$; $p \leq 0.05$).

The $VO2_{max}$ values were significantly correlated to the mean VO2 values during play when examining all subjects together ($r = 0.673$; $p \leq 0.05$) while no significant relationship was found in the female and male groups ($r = 0.548$ and 0.656; $p > 0.05$). The $VO2_{max}$ values were also significantly correlated to the mean PAM values during play in both female and male groups ($r = 0.936$ and 0.962; $p \leq 0.05$) (see Figure 5); while no significant relationship was found when examining all subjects together although the p level indicated a trend ($r = 0.607$; $p = 0.063$).

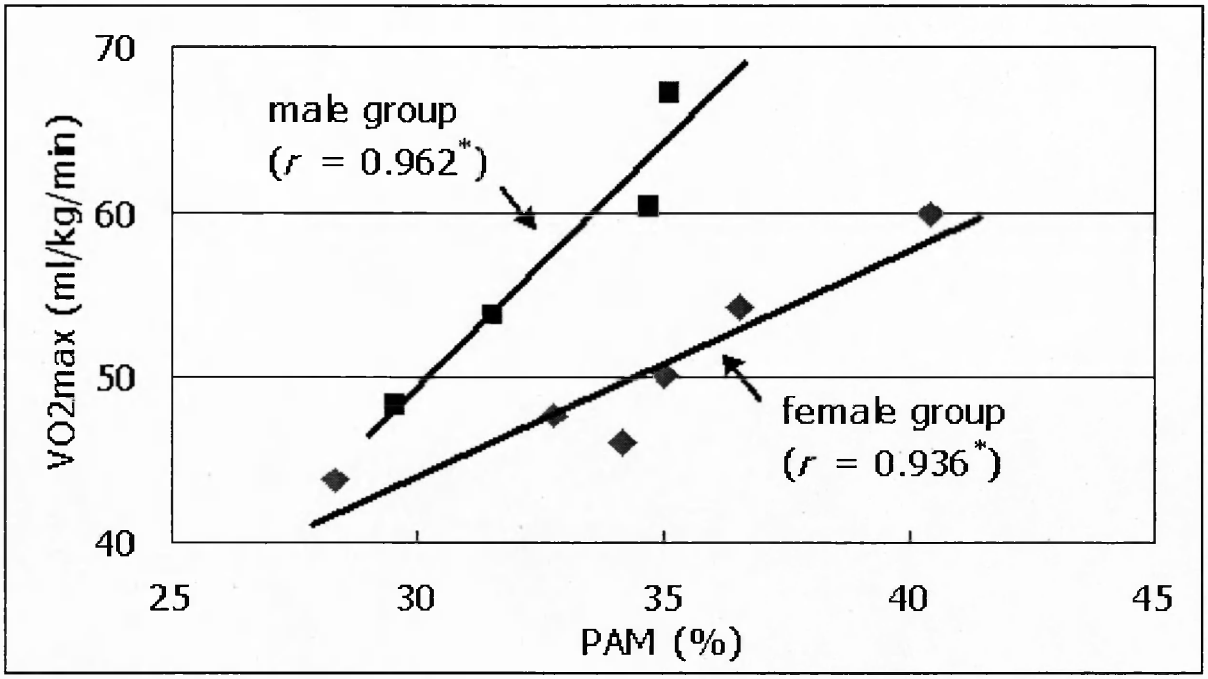

Figure 5. Relationship between $VO2_{max}$ and PAM. The diamond and cube indicate scores of female (n = 6) and male (n = 4) subjects, respectively. Asterisk (*) indicates significant relationship between two variables in each group ($p \leq 0.05$).

Chapter 6 – Discussion

Although several investigators have directly assessed basketball games and scrimmages using time-motion analysis (Taylor, 2003; Taylor, 2004), measuring physiological variables (Rodriguez-Alonso et al., 2003), and conducting both (McInnes et al., 1995), bioenergetic traits of actual basketball performance have been still largely unknown. However, it has been conventionally thought that anaerobic metabolism is the primary energy source playing basketball, and thus, anaerobic conditioning is recommended more than considerably important to perform this sport successfully (Crisafulli et al., 2002; Hunter et al., 1993; McInnes et al., 1995; Tavino et al., 1995; Taylor, 2004). To bring objective and sound insights into the bioenergetics of basketball, more complete assessment including both aerobic and anaerobic observations should be performed during actual basketball performance. This study is considered one of the first to directly measure oxygen consumption during team basketball scrimmages. In this chapter, research findings of this study are discussed in accordance with the hypotheses listed in Chapter 2.

Oxygen Consumption Playing Basketball

As hypothesized, the collegiate basketball players demonstrated relatively high mean VO2 values, 33.4 ± 3.6 and 37.0 ± 2.4 ml/kg/min (66.7 and 64.8 $\%VO2_{max}$) for the females and males, respectively, playing basketball. These values are equivalent to 9.5 and 10.6 METs and are 18.8 and 32.5 % higher than the metabolic cost that Ainsworth et al. (2000) identified for competitive basketball performance (i.e., 8.0 METs). Interestingly, these aerobic costs are also equivalent to those in continuous horizontal running at 149.5 and 167.5 m/min (5.6 and 6.2 mph). It is noteworthy perhaps that the female and male basketball players in this study used only about one-third (34.1 %) of total play time to perform active movements (i.e., runs and jumps). The HR and BLC observed in the female group was of similar level to those previously measured in practice games (i.e., 170 ± 11 bpm and 2.7 ± 1.2 mmol/L) (Rodriguez-Alonso et al., 2003). Also, HR observed in the male group was close to that previously measured in official and practice games (i.e., 168 ± 9 bpm) (McInnes et al., 1995). Consequently, the scrimmages performed in this study appear to provide physiological data typical of actual game play.

These results suggest that competitive collegiate basketball requires extensive utilization of aerobic metabolism. One possible mechanism underlying this is that a fast rate of PC (phosphocreatine) restoration is required during basketball to sustain high-intensity intermittent movements. This restoration has been considered largely dependent on aerobic metabolism (Piiper & Spiller, 1970). In other words, due to chronic adaptation through daily practice, these competitive players may be able to depend on aerobic metabolism to meet much of the energy cost of these high intensity intermittent movements. The significant relationship between the VO2 and PAM values for every 20-second interval ($p \leq 0.05$) may demonstrate the rapid VO2 kinetics playing basketball. Aerobic metabolism may be employed also to sustain low-intensity movements throughout the play. The results of time-motion analysis revealed that more than half of the play time (56.9 %) was spent walking (see Table 10). While walking and generating relatively low-intensity runs, aerobic metabolism may be used as the primary energy source in SO (slow-oxidative) and/or FOG (fast-oxidative-glycolytic) muscle fibers. Aerobic metabolism may also be enhanced during basketball to perform some biological tasks required to compensate for a variety of physiological disturbances, such as disposal of accumulated lactate and heat dissipation. Additionally, with increased body temperature, the VO2 would be elevated by the Q10 effect (Foss & Keteyian, 1998). Stimulation of sympatho-adrenal axis in competitive play may also cause the elevation of oxygen consumption.

Since the above factors are considered to have no small effects on the quality of performance, and furthermore on results of games, aerobic conditioning may be more important than previously realized. Very interestingly, the correlation analysis revealed that the $VO2_{max}$ was significantly correlated to mean VO2 ($r = 0.673$ for all subjects; $p \leq 0.05$) and PAM ($r = 0.936$ and 0.962 for the female and male groups; $p \leq 0.05$) calculated for the entire play time. These results suggest that enhancement of aerobic capacity (i.e., aerobic conditioning) may be beneficial to improve the quality of performance in basketball.

Bioenergetic Traits of Female and Male Basketball

Aerobic Metabolism

The male subjects demonstrated significantly greater $VO2_{max}$ than the female subjects when represented with the allometric scale (i.e., $ml/kg^{0.67}/min$) ($p \leq 0.05$) but not significantly greater when the general linear-relative scale (i.e., ml/kg/min) was used ($p > 0.05$). Several investigators consider that the allometric scaling is biologically more appropriate than the linear-relative expression to equate the aerobic capacities from individuals having various body sizes (Buresh & Berg, 2002; Welsman, Armstrong, Nevill, Winter & Kirby, 1996). However, because the correlation between $VO2_{max}$ and body weight was considerably greater for the allometric scale ($r = 0.496$ vs. 0.058; $p >$ 0.05), i.e., the allometric scale is biased more by body weight, the linear-relative expression is considered proper at least for the present subjects. Based on this observation, it is considered that the aerobic capacity of the male subjects was not significantly greater than that of the female subjects ($p > 0.05$). Similarly, during the scrimmages, the VO2 was not significantly different while the $\%VO2_{max}$ and HR, as well as the RPE, were at almost the same level between these groups ($p > 0.05$). From these findings, as well as from the results of the time-motion analysis indicating a similar pattern of movements between the groups, the aerobic demand is considered not largely different between the male and female basketball.

Interestingly, the results of correlation analysis demonstrated that the VO2 (ml/kg/min) was well correlated to HR in the male subjects during the play ($r = 0.811$ when examining in 20-second intervals and $r = 0.782$ when examining in PPs; $p \leq 0.05$) but such relationships were not observed for the female subjects. It was previously suggested that HR may not be highly correlated to VO2 during some team sports due to upper-extremity movements and cardiovascular drift (Paterson, 1979; Tumilty, 1993). The female subjects may be affected by these factors more than the male subjects.

Anaerobic Metabolism

Relatively low levels of the BLC were observed for both female and male subjects. The mean BLC values (3.2 ± 0.8 and 4.1 ± 1.2 mmol/L, respectively) indicate that both groups performed the scrimmages with only moderate utilization of glycolysis. One possible explanation is that through the chronic adaptation brought by the daily practice, these competitive players may have attained a sport-specific capacity to perform the given task without recruiting large number of the FT (first-twitch) muscle fibers and/or remove lactate from the working muscle fibers effectively (e.g., increase of protein carriers and enzymes). Another explanation is that as Rodriguez-Alonso et al., (2003) previously suggested, the team scrimmage may allow the subjects to regulate the pace or intensity of performance to minimize unduly high lactate accumulation and fatigue. Also, the work-rest ratio during play (i.e., work: 34.1 % vs. rest: 65.9 %) may limit utilization of anaerobic glycolysis.

Although there was no significant difference ($p > 0.05$), 28.1 % higher BLC was observed in the male subjects. However, the time-motion analysis did not reveal differences in the percent of active movements between males and females (see Table 10). Since the BLC was significantly and fairly related to the body weight when examining all subjects together ($p \leq 0.05$), some mechanism involving the body weight may exist to explain greater BLC level in the male subjects.

Energy Expenditure

Both the female and male groups expended considerably large energy through the short-duration (23 minutes) scrimmages (239.0 and 356.5 kcal, respectively). The associated energy expenditure rates during play were 11.2 and 16.9 kcal/min, respectively. These values were significantly (49.2 and 50.2 %) larger in the male subjects ($p \leq 0.05$) simply due to their larger body size. As mentioned before, this energy may be used not only to generate movements (i.e., contract muscle fibers) aerobically and anaerobically but also to execute other physiobiological functions, such as removal of lactate and other metabolites and heat dissipation. These findings suggest that both female and male basketball players need to maintain sufficient level of daily energy uptake for successful conditioning. For instance, if daily practice includes about an hour of scrimmage or similar drills, female and male players need an additional 700 and 1000 kcal, respectively, to maintain energy balance. These data provide an objective estimation of extra energy intake for basketball players, and to my knowledge, these are the first recommendations made based on direct spirometry during actual conditions.

Traits of Movements in Playing Basketball

Unexpectedly, the female and male subjects in this study demonstrated similar patterns of movement during play. Specifically, in both groups, about one-third of play time was spent performing relatively high-intensity movements including running and jumping; while more than half of time was used to walk and about 10 % to stand. On average, about 16 to 17 jumps were made by each player during about 20-minute play time. The mean duration per movement event was roughly 4.0 to 4.5 seconds for run and 5.5 to 6.0 seconds for walk. These findings could be useful for coaches to develop sport-specific training programs and/or drills. For instance, conditioning programs to enhance sport-specific fitness might be more effective if the sets, duration, and/or work/rest ratios were based on the results of time-motion analysis (Taylor, 2004). However, the criteria of the time-motion analysis did not clearly identify the intensity of the respective runs and walks (see Table 5). Therefore, further assessment with more sophisticated criteria including determination of the intensity would be helpful.

Change of Bioenergetic Traits across Playing Periods in Scrimmage

It was originally hypothesized that bioenergetic and physiological variables including VO2, HR, BLC, RPE, and PAM are significantly altered (i.e., impaired) across the playing periods in the scrimmage mainly due to fatigue. However, significant differences were found only for the HR and RPE across the playing periods ($p \leq 0.05$) (see Figure 4). Moreover, contrary to the hypothesis, only RPE scores consistently increased over the course of the scrimmage; while no explicit patterns were found on the change of the other variables including VO2, HR, BLC, and PAM. One possible mechanism for this discrepancy is that the subjects may have employed a pacing strategy, i.e., they may have consciously or subconsciously regulated the pace and/or intensity of movements to maximize performance without causing irreparable harm to physiological systems (Ansley, Schabort, Gibson, Lambert & Noakes, 2004). The pacing strategy has been observed and/or speculated in previous studies regarding several timed events including long distance cycling (Ansley et al., 2004), running (Billat, Slawinski, Danel & Koralsztein, 2001), and kayaking (Bishop, Bonetti & Dawson, 2002). As the results of using this strategy, the variables, which are related to fatigue status, may not demonstrate a consistent pattern of change. In contrast, the perceived exertion (i.e., RPE) may be affected by other factors such as central and mental fatigue which may rise independently of VO2, HR, and BLC. Declines of availability of neurotransmitters and/or blood glucose level are considered part of factors causing central and cognitive fatigue. Also, the finding of no significant relationships between RPE and any of the other variables (*p* > 0.05) may indicate that RPE is limited in predicting the other variables playing basketball and vice versa.

Relationships between Variables in Playing Basketball

It was hypothesized that in playing basketball, an indicator of exercise intensity (i.e., PAM) is significantly related to the bioenergetic and physiological variables (i.e., VO2, HR, and BLC). Unexpectedly, the results of the correlation analysis suggested that only VO2 seems to be related to PAM. However, the correlation between VO2 and PAM is still not as strong as that in experimental steady-state tasks (Foss & Keteyian, 1998). One possible mechanism underlying this is that there may be a considerable time-lag between actual intermittent movement and physiological response playing basketball. This time-lag may dampen the relationships between the variables. Other possible mechanism is that the variables may be also affected by upper-extremity movements, which were not quantified in the present study by PAM. In either case, it is suggested that PAM is not able to be depicted by standard physiological variables such as VO2, HR, and BLC playing basketball.

Limitations and Recommendations

Although this study brought several novel insights into the bioenergetic traits of actual basketball performance, several limitations should be explained. First, the criteria of the time-motion analysis did not classify the intensity of respective movements (see Table 5). To fully address bioenergetic mechanisms underlying actual basketball performance, as well as to provide more useful information to develop sound conditioning programs, exercise intensity should be quantified using objective methodologies. As discussed in Chapter 3, identifying velocity would be one possible way to objectify the intensity of movements. Other measurement tools, such as motion analysis systems featuring triangulation (Castagna, D'ottavio & Abt, 2003) and global positioning system (GPS) (Karboviak, 2005), may be useful to quantify velocity during play. Based on such measurements, more sophisticated criteria including determination of the intensity may be able to be developed. Moreover, if exercise intensity for upper-extremity movements can be also determined by any objective means and incorporated into the criteria, more complete observations may be able to be performed.

Second, BLC and RPE were measured only for each playing period (i.e., four measurements for each variable) and this frequency may be insufficient to fully observe the traits of anaerobic glycolytic metabolism and the change of perceived exertion during play. Experimental settings including frequent measurement of these variables may be more helpful to investigate these traits in detail. Moreover, regarding the assessment for anaerobic metabolism, other experimental tools using spirometry, such as CO2 excess (Crisafulli et al., 2002) and AOD (accumulated oxygen deficit) (Spencer & Gastin, 2001; Tabata et al., 1997), may be useful.

Third, the resolution of VO2 measurement employed in this study (i.e., 0.05 Hz) was somewhat low to fully investigate bioenergetic traits of intermittent movements during play although it was the highest possible resolution in this study. For instance, to investigate VO2 kinetics for respective intermittent movements more accurately, VO2 values should be measured with higher sampling frequency. Although the portable metabolic measurement system used in this study did not allow acquisition of VO2 data using breath by breath method, it may be helpful to overcome this limitation.

Finally, this study assessed bioenergetic traits of basketball performance by gender. However, as the previous studies demonstrated (Caterisano et al., 1997; Rodriguez-Alonso et al., 2003), bioenergetic traits may be considerably altered by positions and/or competition levels. Therefore, future investigations with such analysis would be meaningful.

Chapter 7 – Summary and Conclusions

The purpose of this study was to describe and assess bioenergetic traits of actual basketball performance in collegiate female and male players by measuring VO2, HR, BLC, as well as RPE, and performing a time-motion analysis in team scrimmages. This study provided several novel insights regarding the bioenergetics of this sport.

The collegiate basketball players demonstrated relatively high mean VO2 values, 33.4 ± 3.6 and 37.0 ± 2.4 ml/kg/min (66.7 and 64.8 %$VO2_{max}$) for the females and males, respectively, playing basketball. These values are equivalent to 9.5 and 10.6 METs and 18.8 and 32.5 % higher than the metabolic cost that Ainsworth et al. (2000) identified for competitive basketball performance. Additionally, $VO2_{max}$ of these subjects were significantly correlated to VO2 ($r = 0.673$ for all subjects; $p \leq 0.05$) and PAM ($r = 0.936$ and 0.962 for the female and male groups; $p \leq 0.05$) during play. These players also demonstrated relatively low mean BLC values (3.2 ± 0.8 and 4.1 ± 1.2 mmol/L for the females and males, respectively) playing basketball. They spent 34.1 % of play time performing relatively high-intensity movements (running and jumping); while 56.9 % of time was used to walk and 9.0 % to stand. No significantly different bioenergetic traits were observed between the female and male players during play ($p > 0.05$), except that the male players expended significantly greater energy through the scrimmages (49.2 %; $p \leq 0.05$). Although significant differences were found in HR and RPE scores across the playing periods in the scrimmages ($p \leq 0.05$), only RPE scores demonstrated consistent increase (i.e., impairment) over the course of the scrimmage; while no explicit patterns were found on the change of the other variables including VO2, HR, BLC, and

PAM. A moderate relationship was found between PAM and VO2 during the scrimmages ($r = 0.342$; $p \leq 0.05$), but such relationships were not observed between PAM and other variables including HR, BLC, and RPE ($p > 0.05$). To further assess bioenergetic traits of basketball performance, more detailed research would be helpful. Such research may incorporate sophisticated criteria and measurements to classify exercise intensity in the time-motion analysis, higher resolution of measurements for aerobic and anaerobic measurements, and/or observations of different positions and competition levels.

In conclusion, this study is considered one of the first to investigate bioenergetic traits of basketball performance using direct measurement of oxygen consumption during actual basketball scrimmages. This study revealed greater utilization of aerobic metabolism playing basketball than previously expected and demonstrated other specific bioenergetic traits of female and male collegiate basketball. The findings and implications from this study may provide useful information for basketball coaches and other field professionals to develop sound training programs for basketball players which are essential to promote physical conditioning, and consequently, to improve quality of performance.

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Appendix A – Informed Consent Form

THE ADULT CONSENT FORM

BIOENERGETICS AND TIME-MOTION ANALYSIS OF COMPETITIVE BASKETBALL

INVITATION

You are invited to take part in this research study. The information in this form is meant to help you decide whether or not to take part. If you have any questions, please ask.

WHY ARE YOU BEING ASKED TO BE IN THIS RESEARCH STUDY?

You are being asked to be in this study because you play basketball on the University of Nebraska at Omaha (UNO) men's or women's basketball team and are between the ages of 19 and 35 years. You may participate if are free from any major cardiovascular risks and musculoskeletal problems. If you are pregnant, nursing an infant, or plan to become pregnant during this study, you may not be in this study.

WHAT IS THE REASON FOR DOING THIS RESEARCH STUDY?

The purpose of this study is to determine to what extent and how energy systems are used for basketball performance during team scrimmages.

WHAT WILL BE DONE DURING THIS RESEARCH STUDY?

You will be asked to play basketball in 20 minutes team scrimmages six times over two weeks with other participants from your team. These scrimmages will be conducted at the UNO Sapp Field House and designed as in the same way as real games with cooperation of the participants, coaches and referees, including time-outs and substitutions. You will be asked to be either "Type-A" or "Type-B" participant. Your participation type may be determined during this informed consent process.

If you will be assigned as "Type-A" participant, you will play as a subject of data collection in any one of the six team scrimmages and play as one of non-subject players in other five scrimmages. If you will be a "Type-A" participant and when you will be the subject, you will be asked to wear a breathing mask and a portable monitoring device while playing. At regular intervals while playing, blood sample will be drawn from your ear lobe(s), as well as you will be asked to rate the degree of your perceived exertion. If you will be assigned as "Type-B" participant, you will play as one of non-subject players in all the six scrimmages.

If you will be a "Type-A" participant, you will also be asked to participate in the preliminary testing at the UNO Exercise Physiology Laboratory. After measuring your height and weight, skinfold thickness will be measured at three sites of your body to estimate your body fatness. Then, you will be asked to engage in a treadmill test to identify your maximal aerobic power while running. You will be asked to wear a breathing mask and a portable monitoring device while walking/running. During the test, you will be asked to rate the degree of your perceived exertion every three minutes. Also, a blood sample will be drawn from your ear lobe(s) right before the start and after the end of the treadmill testing.

You will be asked to avoid having high intensity and/or volume of physical activities within 24 hours before each session. Also, you will be asked to avoid eating for several hours before each session. Additionally, you will be asked to stay well hydrated the day before and the day of each session.

WHAT ARE THE POSSIBLE RISKS OF BEING IN THIS RESEARCH STUDY?

Potential risks associated with performing a treadmill test as well as playing basketball in the scrimmages include injuries to the muscles, ligaments, tendons, and joints, fainting, dizziness, disorders of the heart rhythm, and very rare instances of heart attack, stroke, or even death.

Potential risks associated with drawing blood sample include pain and infection.

Potential discomfort associated with playing basketball in the scrimmages with the portable monitoring device includes perception of breathing difficulty.

WHAT ARE THE POSSIBLE BENEFITS TO YOU?

After the completion of this study, you will be invited to attend a presentation given by the investigators regarding the results of this study. From this presentation, you may be able to obtain scientific findings about aerobic and anaerobic traits of actual basketball performance and some practical implications. Additionally, if you will be assigned as a "Type-A" participant, you will receive a summary report about your results in the preliminary testing and the scrimmage. You may be able to utilize these findings, implications, and/or individual results to develop/improve your training programs. You may not get any benefit from being in this research study.

WHAT ARE THE POSSIBLE BENEFITS TO OTHER PEOPLE?

Other people in society may also obtain scientific findings about aerobic and anaerobic traits of actual basketball performance and some practical implications through publications and/or presentations in professional meetings. By applying these findings and implications, basketball coaches and related field professionals as well as competitive and recreational basketball players may be able to make their training programs more reasonable, effective, and/or safe.

WHAT ARE THE ALTERNATIVES TO BEING IN THIS RESEARCH STUDY?

Instead of being in this research study, you can choose not to participate.

WHAT WILL BEING IN THIS RESEARCH STUDY COST YOU?

There is no cost to you to be in this research study.

WILL YOU BE PAID FOR BEING IN THIS RESEARCH STUDY?

You will not be paid to be in this research study.

WHAT SHOULD YOU DO IF YOU ARE INJURED OR HAVE A MEDICAL PROBLEM DURING THIS RESEARCH STUDY?

Your safety is the major concern of every member of the research team. If you are injured or have a medical problem as a result of being in this study, you should immediately contact one of the people listed at the end of this consent form. Immediate emergency medical treatment for this injury will be available at the Nebraska Medical Center. There will be no charge to you for this care provided you have followed all instructions and medical advice and done nothing to cause or contribute to the injury. The costs for any other medical problems unrelated to this research study are your responsibility. There are no plans to provide payment for things like lost wages, disability or discomfort. You or your insurance company will need to pay for any costs. Agreeing to this does not mean you have given up any of your legal rights.

HOW WILL INFORMATION ABOUT YOU BE PROTECTED?

You have rights regarding the privacy of your health information collected before and during this research. This information, called "protected health information" (PHI), includes demographic information (like your address and birth date), the results of your exercise tests, as well as your medical history. You have the right to limit the use and sharing of your PHI, and you have the right to see your records and know who else is seeing them.

By signing this consent form, you are allowing the research team to have access to your PHI. The research team includes the investigators listed on this consent form and other personnel involved in this specific study at the UNO.

Your PHI will be used only for the purpose(s) described in the section "What is the reason for doing this research study?"

Your PHI will be shared, as necessary, with the Institutional Review Board (IRB) and with any person or agency required by law. You are also allowing the research team to share your PHI with other people or groups listed below. All of these persons or groups listed below are obligated to protect your PHI.

You are authorizing us to use and disclose your PHI for as long as the research study is being conducted.

You may cancel this authorization to use and share your PHI at any time by contacting the principal investigator in writing. If you cancel this authorization, you may no longer participate in this research. If you cancel this authorization, use or sharing of future PHI will be stopped. The PHI which has already been collected may still be used.

The information from this study may be published in scientific journals or presented at scientific meetings but your identity will be kept strictly confidential.

WHAT ARE YOUR RIGHTS AS A RESEARCH SUBJECTS?

You have rights as a research subject. These rights have been explained in this consent form and in *The Rights of Research Subjects* that you have been given. If you have any questions concerning your rights, talk to the investigator or call the Institutional Review Board (IRB), telephone (402) 559-6463.

WHAT WILL HAPPEN IF YOU DECIDE NOT TO BE IN THIS RESEARCH STUDY?

You can decide not to participate in this study or you can withdraw from this study at any time. Your decision will not affect your care or your relationship with the investigator, the UNO, the University of Nebraska Medical Center or the Nebraska Medical Center. Your decision will not result in any loss of benefits to which you are entitled.

DOCUMENTATION OF INFORMED CONSENT

You are freely making a decision whether to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered and (4) you have decided to be in the research study. If you have any questions during the study, you should talk to one of the investigators listed below. You will be given a copy of this consent form to keep.

Signature of Subject:	Date:	Time:

My signature as witness certifies that the subject signed this consent form in my presence as their voluntary act and deed.

Signature of Witness:	Date:	Time:

My signature certifies that all the elements of informed consent described on this consent form have been explained fully to the subject. In my judgment, the participant possesses the legal capacity to give informed consent to participate in this research and is voluntarily and knowingly giving informed consent to participate.

Signature of Investigator:	Date:	Time:

My signature certifies that I have authorized the investigator signing above to document the obtainment of informed consent, and he/she has the necessary clinical expertise and sufficient knowledge about the protocol and IRB consent requirements to document obtainment of consent. In my judgment, valid informed consent has been obtained from the subject.

Signature of PI:	Date:	Time:

AUTHORIZED STUDY PERSONNEL

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Appendix B – Medical History Form

Medical History Form

Date: ____________________ Age: ____________________

Name: ____________________ Sex: ____________________

Address: ____________________ Weight (lbs.): ____________________

Employment: ____________________ Height (inch): ____________________

Address: ____________________

Phone: ____________________ (home)

Phone: ____________________ (work)

Name of Personal Physician: ____________________

Address: ____________________

Have you been hospitalized within the last two years? ____________________

If yes, please explain:

____

____

____

Check the following which have occurred in your past medical history:

Heart Attack __________

High Blood Pressure __________

Chest Discomfort __________

ECG Abnormality __________

Stroke __________

Obesity __________

Unexplained Weight Gain or Loss __________

Diabetes __________

Arthritis, Bursitis, Gout or Joint Inflammation __________

Epilepsy __________

Asthma __________

Emphysema __________

Bronchitis __________

Shortness of Breath __________

Lightheadedness or Fainting __________

Heat Illness __________

Allergy __________

Other (explain) __________

____

List any medication(s) you are presently taking and condition(s) being treated.

____

____

____

List and describe any condition you have which may affect your ability to participate in strenuous physical activity.

____

____

____

Any family history of: (check if yes and indicate age of occurrence)

	Age of Occurrence	Who (mother, father, sibling aunt, uncle, grandparents)
Death before age 60	________	________________
Heart disease	________	________________
High blood pressure	________	________________
Diabetes	________	________________
Stroke	________	________________
Obesity	________	________________
Asthma	________	________________
Emphysema	________	________________

Weight History (lbs.)

High-school graduation	________	One year ago	________
Now	________	Maximum ever	________
		When?	________

Smoking History

Ever?	________	Now?	________
What?	________	How often?	________
How much?	________	Attempted to stop?	________

Physical Activity History

Describe any physical activities that you have participated in during the last 12 months.

Activity	# of days per week	# of minutes per session	# of weeks/months of involvement
______________	______________	______________	______________
______________	______________	______________	______________
______________	______________	______________	______________

Describe any physical activities that you have participated in during the last 6 weeks.

______________	______________	______________	______________
______________	______________	______________	______________
______________	______________	______________	______________

Pregnancy and/or breast feeding (<u>only females</u>)

Are you currently a pregnant or breast feeding woman? ______________

Do you currently have child-bearing potential? ______________

Appendix C – Data Collection Sheet for Preliminary Testing

Basketball Study Data Collection Sheet: Preliminary Testing

Name: ______________________________ Date: ___________________

Age: _____________ DOB: _________________________

Height: ___________ in. Weight: _________ lbs.

Skinfold Site	Trial 1	Trial 2	Trial 3
Thigh:	________ mm	________ mm	________ mm
Triceps (F)/Abdomen (M):	________ mm	________ mm	________ mm
Suprailium (F)/Chest (M):	________ mm	________ mm	________ mm

SS: ________ mm

Treadmill GXT	Speed	BLC	HR	RPE
PRE:		_____ mmol/L	______ bpm	
STG1:	3 mph		______ bpm	________
STG2:	_____ mph		______ bpm	________
STG3:	_____ mph		______ bpm	________
STG4:	_____ mph		______ bpm	________
STG5:	_____ mph		______ bpm	________
STG6:	_____ mph		______ bpm	________
STG7:	_____ mph		______ bpm	________
STG8:	_____ mph		______ bpm	________
STG9:	_____ mph		______ bpm	________
STG10:	_____ mph		______ bpm	________
POST:		_____ mmol/L	______ bpm	________

Appendix D – Data Collection Sheet for Field Testing

Basketball Study Data Collection Sheet: Field Testing

Name: ______________________ Date: ______________

Age: __________ DOB: __________________

Weight: _________ lbs.

Time-outs	BLC	HR	RPE
PRE:	____ mmol/L	____ bpm	
1ST TO:	____ mmol/L	____ bpm	______
2ND TO:	____ mmol/L	____ bpm	______
3RD TO:	____ mmol/L	____ bpm	______
POST:	____ mmol/L	____ bpm	______

	Sync Time	Clock Time
23:00 Call Play #1 (5 minutes)	______	______
18:00 Call Official Time Out #1 (1 minute)	______	______
17:00 Call Play #2 (5 minutes)	______	______
12:00 Call Official Time Out #2 (1 minute)	______	______
11:00 Call Play #3 (5 minutes)	______	______
6:00 Call Official Time Out #3 (1 minute)	______	______
5:00 Call Play #4 (5 minutes)	______	______
0:00 Call End	______	______