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Physiological demands of competitive basketball

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The aim of this study was to assess physiological demands of competitive basketball by measuring oxygen consumption (VO_2) and other variables during practice games. Each of 12 players (20.4 ± 1.1 years) was monitored in a 20-min practice game, which was conducted in the same way as actual games with the presence of referees and coaches. VO_2 was measured by a portable system during the game and blood lactate concentration (LA) was measured in brief breaks. Subjects were also videotaped for time-motion analysis. Female and male players demonstrated respective VO_2 of 33.4 ± 4.0 and 36.9 ± 2.6 mL/kg/min and LA of 3.2 ± 0.9 and 4.2 ± 1.3 mmol/L in the practice games ($P > 0.05$). They spent 34.1% of play time running and jumping, 56.8% walking, and 9.0% standing. Pre-obtained VO_{2max} was correlated to VO_2 during play ($r = 0.673$) and to percent of duration for running and jumping ($r = 0.935$ and 0.962 for females and males, respectively). This study demonstrated a greater oxygen uptake for competitive basketball than that estimated based on a previous compendium. The correlation between aerobic capacity and activity level suggests the potential benefit of aerobic conditioning in basketball.

Basketball has gained worldwide popularity and fascinated players and spectators with its dynamic characteristics as a team sport (Hoffman & Maresh, 2000). In this sport, players cover about 4500–5000 m during a 40-min game with a variety of multidirectional movements such as running, dribbling, and shuffling at variable velocities and jumping (Crisafulli et al., 2002). To execute such movements during performance, both aerobic and anaerobic metabolic systems appear to be involved throughout a game (Ciuti et al., 1996). However, it has been conventionally thought that anaerobic metabolism is the primary energy pathway in playing basketball, and thus, anaerobic conditioning has been emphasized in practice (Hunter et al., 1993; McInnes et al., 1995; Tavino et al., 1995; Crisafulli et al., 2002; Taylor, 2004).

Up to this point, many studies have investigated physiological and metabolic demands of this sport through a variety of assessments, such as survey and self-report (Latin et al., 1994; Berg & Latin, 1995; Ainsworth et al., 2000), physical and physiological tests (Gillam, 1985; Hoffman et al., 1991; Hunter et al., 1993; Tavino et al., 1995; Caterisano et al., 1997; LaMonte et al., 1999), field tests with tasks including basketball-like movements (Hoffman et al., 1999; Crisafulli et al., 2002), and time-motion analysis (McInnes et al., 1995; Taylor, 2003, 2004) or other game analysis (Hoffman et al., 1996). Additionally, some studies measured physiological variables including heart rate (HR) and blood lactate concentration (LA) in actual basketball games (McInnes et al., 1995; Rodriguez-Alonso et al., 2003). These two studies demonstrated relatively high physiological demands of competitive basketball, as evidenced by the elevated LA and sustained high HR response despite the relatively low percent of live time spent in high-intensity activities (McInnes et al., 1995; Rodriguez-Alonso et al., 2003).

Despite a number of previous studies, findings regarding physiological demands, especially aerobic demands of *actual* basketball performance have been limited (Ciuti et al., 1996; Crisafulli et al., 2002; Rodriguez-Alonso et al., 2003). To our knowledge, no direct measurement of oxygen consumption in actual basketball game play has yet been performed. Although HR was measured during actual games (McInnes et al., 1995; Rodriguez-Alonso et al., 2003), it is limited as an indicator of aerobic metabolism during basketball games potentially due to upper-extremity movements and/or cardiovascular drift (Paterson, 1979; Tumilty, 1993). To enhance knowledge for developing sound training and nutrition programs, direct assessment of aerobic metabolism should be helpful.

Therefore, the purpose of this study was to assess physiological responses of competitive collegiate basketball by measuring oxygen consumption (VO_2), HR, LA, and perceived exertion (RPE), as well as performing a time-motion analysis in practice games. For this purpose, we developed and tested the following four hypotheses: (1) during the practice games, both male and female varsity players will demonstrate greater VO_2 than 28.0 mL/kg/min estimated based on a previously reported compendium (Ainsworth et al., 2000; American College of Sports Medicine, 2006), (2) VO_2, HR, LA, and RPE will be greater in male than female players during the games, (3) VO_2, HR, LA, and RPE will systematically rise across time during the games, and (4) significant correlations will be observed between VO_{2max} and VO_2, HR, LA, RPE, and the percent of duration for active movements including runs and jumps (PAM).

Through the assessment, we elucidated aerobic and anaerobic traits of male and female collegiate basketball players and demonstrated that aerobic demand for these players is considerably higher than previously expected (Ainsworth et al., 2000). Furthermore, we clarified that there were fair to strong correlations between VO_{2max} and VO_2 during playing, as well as VO_{2max} and percent of active movements during playing. Preliminary result of this study was presented in abstract form (Narazaki & Berg, 2006).

Materials and methods

Subjects

Six female (one center, two forwards, and three guards) and six male (two center, two forwards, and two guards) players in the National Collegiate Athletic Association (NCAA) Division II teams were recruited as subjects in this study. Demographic variables of the subjects are summarized in Table 1. Nine of these subjects were starters in the previous season. Before the commencement of any tests, written informed consents were obtained from all the subjects, as well as other players who performed practice games with the subjects. Using a standardized medical history form, all subjects were determined to be healthy and free from any major cardiovascular risks or musculo-skeletal problems. This study was approved by the University of Nebraska Institutional Review Board (IRB).

Experimental design

Within 3 weeks after the completion of the season, each of both female and male teams played six practice games in their regular practice time in 2 non-consecutive days. Because both teams had performed off-season practice after the completion of the season, detraining effect (Mujika & Padilla, 2001) was considered minimal. Specifically, the practice game was designed to mimic one-half of an official game consisting of four playing periods (about 5 min each) and three alternate resting periods (about 1 min each). The practice game was conducted in the same way as actual games with cooperation of all players, coaches, referees, scorers, and spectators to simulate game conditions. A single subject was assigned for each game in advance and played basketball while wearing a portable metabolic measurement system (VO2000; Medical Graphics Corp., St. Paul, Minneapolis, USA) throughout the game. Within 2–3 days before the game, each subject performed a VO_{2max} test.

VO_{2max} test

The subject engaged in a treadmill graded exercise test (GXT) in order to determine the VO_{2max}. The GXT was commenced at a speed of 80.0 m/min and speed was increased by 26.7 m/min every 2 min or by 13.3 m/min every 1 min until the subject reached volitional exhaustion. The portable metabolic measurement system was fitted on the subject's body using a standardized procedure determined by the investigators in advance. The same portable system was used in this test as the one used in the practice games to familiarize the subject with the system. The VO_2 was measured by the system with a sampling frequency of 0.05 Hz, while HR was monitored using a Polar watch (Polar Electro Oy, Kempele, Finland) and RPE was assessed using Borg's original (i.e., 6–20) scale (Borg, 1982) every 1–2 min. After the termination of the test, an intact blood sample was drawn from a finger and the LA was then immediately measured using a lactate analyzer (Accusport; Boeringer Mannheim, Castle Hill, Australia). Peak VO_2 value in a 20-s window during the test was regarded as the subject's VO_{2max} if three of the following four criteria were met at the point of volitional exhaustion: (a) RPE: $\geq$ 19, (b) HR: within 10 b.p.m. of age predicted maximal HR (i.e., 220 − age), (c) LA: $\geq$ 8.0 mmol/L, and (d) VO_2 plateau: difference between the peak VO_2 value and the value in the immediately preceding 20 s is 2.0 mL/kg/min or less. Previous studies confirmed validity and reliability of the portable metabolic measurement system (Byard & Dengel, 2002) and the lactate analyzer (Pinnington & Dawson, 2001).

Practice game

In each day of the experiment, three practice games took place. The first game of the day was preceded by a moderate warm-up including running, dribbling, and shooting for 10–15 min. Two consecutive games were separated by a break of 15–25 min. Before each game, the portable metabolic measurement system was fitted to the subject assigned. Then, the subject and other players were encouraged by the coaches and investigators to play with usual intensity in actual games.

Table 1. Demographic variables of the subjects (M $\pm$ SD)

Variable	Female ($n = 6$)	Male ($n = 6$)
Age (years)	20.0 $\pm$ 1.3	20.8 $\pm$ 1.0
Height (cm)*	174.2 $\pm$ 9.0	192.4 $\pm$ 11.7
Body weight (kg)*	66.9 $\pm$ 5.8	91.9 $\pm$ 17.5
Percent body fat (%)[†]	19.8 $\pm$ 4.5	9.7 $\pm$ 5.9

*Height and body weight were measured using a general combination scale (Detecto Medic; Detecto Scales Inc., Brooklyn, New York, USA).

[†]Percent body fat was estimated based on skinfold measurement for thigh, triceps, suprailium (female) and for thigh, abdomen, and chest (male). Specifically, body density was estimated first from the skinfold measurement by using the Jackson–Pollock and Jackson–Pollock–Ward generalized equations for males and females, respectively (Jackson and Pollock, 1978; Jackson et al., 1980) and next the percent body fat was calculated from the body density using Siri equation (Siri, 1956).

Table 2. Criteria for time-motion analysis

Movement	Description
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

Throughout the practice game, the VO_2 and HR were synchronously measured by the portable metabolic measurement system with a sampling frequency of 0.05 Hz. Additionally, LA and RPE were measured immediately after completing each playing period. In each practice game, the subject assigned was also videotaped by a digital video camcorder (ZR20; Canon U.S.A. Inc., Lake Success, New York, USA) so that his/her lower-extremity movements were captured throughout the game for time-motion analysis. Subjects in the second and third games of the day did not play in the preceding game to avoid excessive fatigue.

Time-motion analysis

After the practice game, time-motion analysis was conducted by one investigator to quantify selected aspects of each subject's performance. Specifically, discrete movements in the game were identified and coded into four types of movements: walk, run, jump, and stand, with a temporal resolution of 1 s using criteria summarized in Table 2. These criteria are based on the type of foot support (i.e., single support, double support, or floating in air) and direction of movement (horizontal or vertical). For instance, for a series of consecutive lateral movements (i.e., shuffling) continued with single and double support phases and without floating phases, all 1-s windows during this movement were coded as walk. If a given 1-s window included a transition of two movements, this 1-s window was coded for the one which was of longer duration. Through this process, duration of respective discrete movements and then frequency and duration of each type of movement were calculated. Furthermore, the percent of duration for active movements comprised just runs and jumps (PAM) was calculated in each of four playing periods and the overall playing periods for further analysis (McInnes et al., 1995).

Test–retest reliability of the time-motion analysis was confirmed by the same investigator re-analyzing data for one female and one male player about 9 months after the original analysis. The comparison of the results in the two separate occasions demonstrated that 94.8% and 94.3% of 1-s windows were coded into the same movements in the female and male subjects, respectively. Furthermore, χ^2 statistics indicated that the distribution of the frequency counts into the four types of movements was statistically similar between the two occasions for the female and male subjects, respectively ($\chi^2 = 3.78$ and 2.10; $P > 0.90$ and 0.95).

Data analysis

Data from all positions were pooled in each gender group and presented as means and standard deviations (M ± SD). Independent t-test was used to compare mean VO_{2max} values between female and male groups. Two-way analysis of variance (ANOVA) for repeated measures was used to compare means in selected variables between genders across four playing periods (i.e., 2×4), as well as across three resting periods (i.e., 2×3). Independent t-test with Bonferroni's correction was used as a *post hoc* test if significant differences were found in the ANOVAs. Additionally, Pearson's correlation coefficient was used to assess relationships between selected variables. All statistical analyses were performed using the SPSS Version 14.0 (SPSS Inc., Chicago, Illinois, USA). Significance level was set at $\alpha = 0.05$.

Results
VO_{2max} test

Because the results of the treadmill GXT for two male subjects did not meet two of the aforementioned criteria (b and c), the VO_{2max} were determined only for six female and four male subjects. The VO_{2max} for female and male groups were 3.36 ± 0.43 and 5.47 ± 0.52 L/min ($t = -7.05$; $P \leq 0.05$) and 50.3 ± 5.9 and 57.5 ± 8.2 mL/kg/min ($t = -1.63$; $P > 0.05$), respectively. The VO_{2max} values were associated with RPE, HR, and LA values of 19.5 ± 0.5 and 19.6 ± 0.5 ($t = -0.37$; $P > 0.05$), 190.7 ± 13.2 and 192.3 ± 7.6 b.p.m. ($t = -0.21$; $P > 0.05$), and 9.1 ± 2.3 and 10.0 ± 1.1 mmol/L ($t = -0.72$; $P > 0.05$) for female and male groups, respectively.

Practice game

Actual playing and resting periods were 18.6 ± 0.3 and 4.4 ± 0.3 min for female group and 18.1 ± 1.2 and 4.9 ± 1.2 min for male group, respectively ($P > 0.05$). All results during the practice game are summarized in Table 3. Representative HR and VO_2 data from a male player are demonstrated in Fig. 1.

The mean VO_2 values during play were 33.4 ± 4.0 mL/kg/min for the female group and 36.9 ± 2.6 mL/kg/min for the male group, respectively

Table 3. Results of measurement during team scrimmage (M ± SD)

Variable	Female ($n = 6$)	Male ($n = 6$)
VO_2 play (mL/kg/min)*	33.4 ± 4.0	36.9 ± 2.6
VO_2 play (%VO_{2max})*	66.7 ± 7.5	64.7 ± 7.0[‡]
VO_2 rest (mL/kg/min)[†]	21.3 ± 2.1	22.8 ± 3.3
VO_2 rest (%VO_{2max})[†]	42.7 ± 6.1	41.1 ± 10.2[‡]
HR play (b.p.m.)*	168.7 ± 11.0[§]	169.3 ± 4.5[§]
HR rest (b.p.m.)[†]	152.5 ± 11.5[§]	150.4 ± 11.4[§]
LA play (mmol/L)*	3.2 ± 0.9	4.2 ± 1.3
RPE play*	14.3 ± 1.9	13.7 ± 1.0

*Mean value for four playing periods.

[†]Mean value for three resting periods.

[‡]$n = 4$.

[§]$n = 5$.

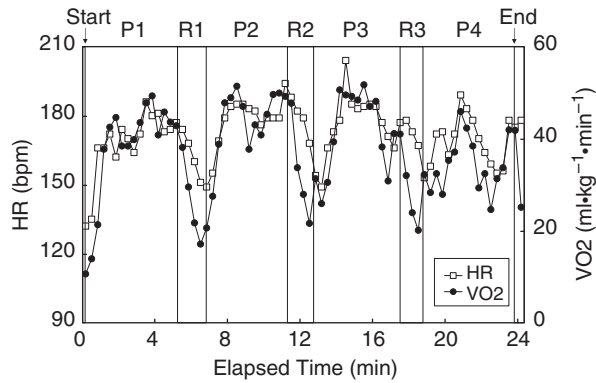No significant differences were found between groups for any measured variables ($P > 0.05$).

Fig. 1. Representative heart rate (HR) and VO_2 data in the practice game of one player. The open cube and closed circle indicate HR and VO_2 values in every 20-s window, respectively. The P and R denote playing and resting periods, respectively. Note that the VO_2 and HR values rose and dropped rapidly at the onset and right after the completion of each playing period, and that they fluctuated considerably during the respective playing periods.

($P > 0.05$). The associated normalized VO_2 values ($\%VO_{2max}$) were $66.7 \pm 7.5\%$ for the female group and $64.7 \pm 7.0\%$ for the male group ($P > 0.05$). The mean VO_2 values during play are 19.3% and 31.8% higher than the value (28.0 mL/kg/min) estimated based on the previously reported compendium by Ainsworth et al. (2000).

There were no significant main effects for groups in all variables measured ($P > 0.05$), while mean values for the female group were slightly lower in the VO_2 (9.5%), HR (0.4%), and LA (23.8%) and higher in the $\%VO_{2max}$ (3.1%) and RPE (4.4%) values than those for the male group during play. Also, mean values for the female groups were slightly lower in the VO_2 (6.6%) and higher in the $\%VO_{2max}$ (3.9%) and HR (1.4%) during rest.

Figure 2 demonstrates changes of the VO_2, HR, LA, and RPE values in the four playing periods. All data were successfully collected from the 12 subjects in the practice games except the HR values for two subjects in all playing periods and the LA value for one subject in one playing period due to technical problems. There were significant main effects for playing periods in the HR ($F = 5.46$; $P \leq 0.05$) and RPE ($F = 20.32$; $P \leq 0.05$). Specifically, the HR values for the second and third playing periods were significantly higher than that for the first period (3.7% and $t = -4.66$, and 3.5% and $t = -3.82$, respectively; $P \leq 0.05$). Also, the RPE values for the second, third, and fourth playing periods were significantly higher than that for the first playing period (15.7% and $t = -7.37$, 18.2% and $t = -5.05$, 28.1% and $t = -7.30$, respectively; $P \leq 0.05$), as well as the fourth period than the second period (10.7% and $t = -3.32$; $P \leq 0.05$). In contrast, the VO_2 and LA values were not significantly different among the
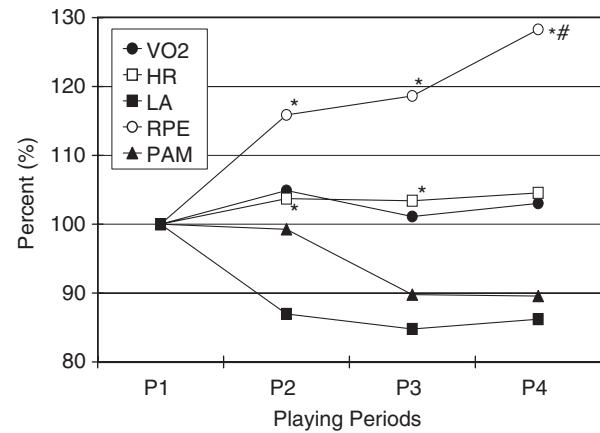

Fig. 2. Relative changes of VO_2, HR, LA, RPE, and PAM values in the four playing periods. The closed circle, open cube, closed cube, open circle, and closed triangle indicate relative VO_2, HR, LA, RPE, and PAM values relative to those in the first period, respectively. The P denotes playing periods. Raw values for these variables are (from P1 to P4): $VO_2 = 34.4 \pm 3.9$, 36.1 ± 4.2, 34.8 ± 4.4, 35.4 ± 4.2 mL/kg/min ($n = 12$); HR = 164.3 ± 7.9, 170.4 ± 9.1, 170.0 ± 10.1, 171.8 ± 8.7 b.p.m. ($n = 10$); LA = 4.1 ± 1.9, 3.6 ± 1.4, 3.5 ± 1.3, 3.5 ± 1.3 mmol/L ($n = 12$ except that $n = 11$ in the P2); RPE = 12.1 ± 2.0, 14.0 ± 1.7, 14.3 ± 1.9, 15.5 ± 1.4 ($n = 12$); PAM = $36.0 \pm 5.3\%$, $35.7 \pm 4.3\%$, $32.3 \pm 4.7\%$, $32.2 \pm 5.5\%$ ($n = 12$), respectively. $*P \leq 0.05$ with P1. $^{\#}P \leq 0.05$ with P2. HR, heart rate; LA, blood lactate concentration; RPE, perceived exertion.

four playing periods ($P > 0.05$). Also, there were no significant main effects for resting periods in the VO_2 and HR values ($P > 0.05$). No interactions (groups × playing or resting periods) were found in any variables measured ($P > 0.05$).

Time-motion analysis

Frequency and duration of respective types of movements are summarized in Figs 3 and 4. Fairly similar results were found in all variables for the two groups. When data from both groups were pooled, $47.0 \pm 1.7\%$, $36.1 \pm 4.2\%$, $9.8 \pm 3.5\%$, and $7.2 \pm 3.0\%$ of frequency counts (i.e., discrete events) were walk, run, stand, and jump, respectively. Also, $56.8 \pm 2.6\%$, $32.6 \pm 3.7\%$, $9.0 \pm 3.9\%$, and $1.5 \pm 0.7\%$ of time was spent performing walk, run, stand, and jump, respectively. The PAM for the overall game was $34.5 \pm 4.0\%$ and $33.7 \pm 3.4\%$ for the female and male groups, respectively. No main effects either for gender or playing periods, as well as no interaction (gender × playing periods), were found in the PAM ($P > 0.05$) (Fig. 2).

Correlation analysis

In all assessable subjects, the VO_{2max} (mL/kg/min) was significantly correlated to mean VO_2 (mL/kg/min) during play ($n = 10$; $r = 0.673$; $P \leq 0.05$). In
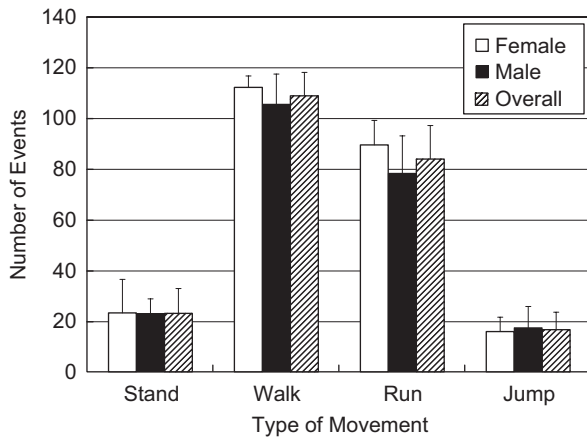
Fig. 3. Frequency counts of discrete movements in female (white bar; $n = 6$), male (black bar; $n = 6$), and overall (diagonal bar; $n = 12$) groups. Raw values for these variables are (for female, male, and overall groups): Stand = 23.2 ± 13.2, 22.8 ± 5.9, 23.0 ± 9.8; Walk = 112.0 ± 4.5, 105.3 ± 11.9, 108.7 ± 9.2; Run = 89.3 ± 9.6, 78.2 ± 14.7, 83.8 ± 13.2; Jump = 15.8 ± 5.7, 17.3 ± 8.4, 16.6 ± 6.9.
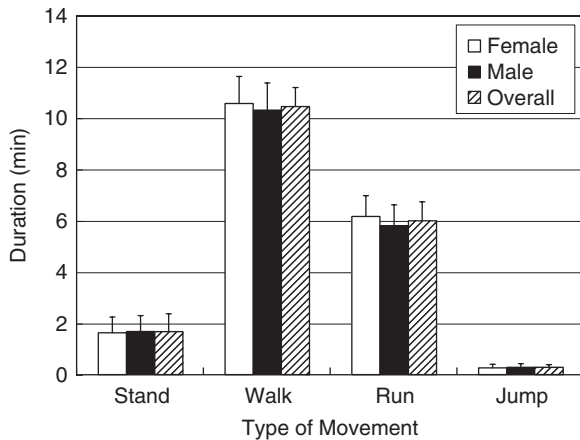

Fig. 4. Total duration for respective types of movements in female (white bar; $n = 6$), male (black bar; $n = 6$), and overall (diagonal bar; $n = 12$) groups. Raw values for these variables are (for female, male, and overall groups): Stand = 1.6 ± 0.9, 1.7 ± 0.6, 1.7 ± 0.7 min; Walk = 10.6 ± 0.3, 10.3 ± 1.1, 10.4 ± 0.8 min; Run = 6.2 ± 0.7, 5.8 ± 0.8, 6.0 ± 0.7 min; Jump = 0.3 ± 0.1, 0.3 ± 0.1, 0.3 ± 0.1 min.

contrast, the VO_{2max} was not significantly related to mean PAM during play while the P level indicated a trend ($n = 10$; $r = 0.609$; $P = 0.062$). However, significant and strong correlations were found when the relationships were examined for females ($n = 6$; $r = 0.935$; $P \leq 0.05$) and males ($n = 4$; $r = 0.962$; $P \leq 0.05$), respectively (Fig. 5).

Discussion

To our knowledge, this is the first study quantifying the VO_2 during competitive basketball play designed
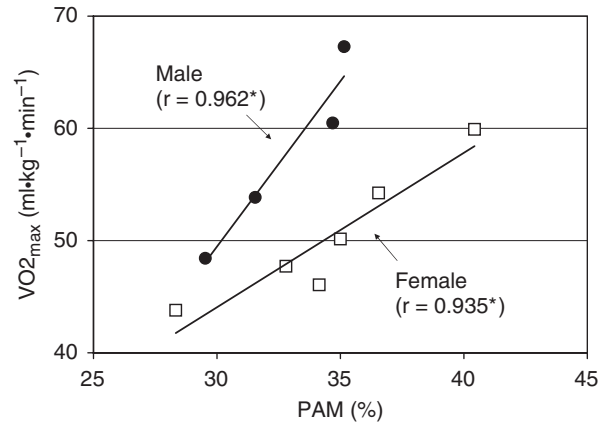

Fig. 5. Relationship between VO_{2max} and PAM. The open cube and closed circle indicate results of female ($n = 6$) and male ($n = 4$) groups, respectively. *$P \leq 0.05$.

to mimic one-half of an official game. Two main findings are obtained from this study: (1) the VO_2 in competitive female and male basketball players was higher than that estimated based on a previously developed compendium (Ainsworth et al., 2000) and (2) there were significant correlations between the subject's VO_{2max} and VO_2 during play for the female and male groups pooled and between the VO_{2max} and PAM in the respective groups. In this section, these and other findings are discussed in accordance with the hypotheses listed in the introduction.

Oxygen consumption playing basketball

The collegiate basketball players demonstrated mean VO_2 values of 33.4 ± 4.0 and 36.9 ± 2.6 mL/kg/min ($66.7 \pm 7.5\%$ and $64.7 \pm 7.0\%$ VO_{2max}) for the females and males, respectively. These values are 19.3% and 31.8% higher than the value for competitive basketball performance (28.0 mL/kg/min) estimated based on the previously reported compendium (Ainsworth et al., 2000). Interestingly, these VO_2 values are equivalent to horizontal running velocities of 149.5 and 167 m/min (9.0 and 10.0 km/h) (American College of Sports Medicine, 2006) while the players in this study used only about one-third (34.1%) of total play time for active movements (i.e., runs and jumps). The HR and LA observed in the female group was of similar level to those previously measured in practice games (i.e., 170 ± 11 b.p.m. and 2.7 ± 1.2 mmol/L) (Rodriguez-Alonso et al., 2003). Also, HR observed in the male group was comparable with that in official and practice games (i.e., 168 ± 9 b.p.m.) (McInnes et al., 1995). These comparisons suggest that the intensity of the practice games in this study were reasonably comparable with that of actual game play despite the use of the portable metabolic measurement system.

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The result for VO_2 values suggests that competitive collegiate basketball requires extensive utilization of aerobic metabolism. While phosphagens are the likely source of much of the energy during basketball, a fast rate of phosphocreatine (PCr) restoration is required to sustain high-intensity intermittent movements. Restoration of PCr is largely dependent on aerobic metabolism (Piiper & Spiller, 1970). Also, aerobic metabolism is likely employed to maintain low-intensity movements throughout play. The time-motion analysis revealed that more than half of the play time (56.8%) was spent walking (Fig. 4). In walking and low-intensity runs, aerobic metabolism is probably the primary energy pathway. 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.

These results suggest the importance of aerobic conditioning for basketball players. Interestingly, the correlation analysis revealed that the VO_{2max} was significantly correlated to mean VO_2 ($r = 0.673$ for both groups pooled; $P \leq 0.05$) and the percent of duration for active movements during play ($r = 0.935$ and 0.962 for the female and male groups, respectively; $P \leq 0.05$) (Fig. 5). These fair to strong correlations may indicate the potential benefit of aerobic conditioning in basketball.

Differences in physiological responses between genders

Similar results were observed for female and male groups in all variables measured in the practice games ($P > 0.05$). Interestingly, relatively low levels of LA values were observed for both female and male groups during play (3.2 ± 0.9 and 4.2 ± 1.3 mmol/L, respectively). A potential explanation of the result is that the "stop and go" nature of basketball may limit the accumulation of LA, i.e., short periods of high-intensity play with accumulation of LA are alternated by periods of reduced intensity play such as walking and standing. At these latter times, LA can be transported and removed from the blood. The time-motion analysis data indicate that only 34.1% of play time is spent running and jumping while 65.8% is spent walking and standing. Therefore, time exists for partial recovery and minimization of LA levels. Another potential explanation is that the chronic training of basketball may also enhance LA removal and explain in part the submaximal LA values.

The female and male groups also 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 16–17 jumps were made by each player during about 20-min of play time. The mean duration per movement event was roughly 4.0–4.5 s for run and 5.5–6.0 s for walk. These findings may 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 (McInnes et al., 1995; Taylor, 2003, 2004).

Systematic changes in physiological responses across time

In contrast to the original hypothesis, significant changes were found only for the HR and RPE across the playing periods ($P \leq 0.05$) and systematic changes in expected directions were observed only for the RPE (Fig. 2). It is interesting to note that the LA dropped 12.2% after the second playing period and remained fairly constant in the rest of the playing periods. One possible explanation for this pattern is that as observed in other athletic events, the subjects in this study may have used a type of pacing strategy, i.e., they may have consciously or subconsciously regulated the pace and/or intensity of movements to maximize performance while minimizing fatigue (Billat et al., 2001; Bishop et al., 2002; Ansley et al., 2004). In fact, the subjects demonstrated slight reduction of the PAM after the third playing periods, which might be a part of such a strategy. Owing to the slight reduction, the physiological variables related to fatigue may not demonstrate a systematic pattern of changes.

Correlation among physiological variables

Correlation analyses were performed between VO_{2max} and mean values of physiological parameters including the VO_2, HR, LA, RPE, and PAM. Fair to strong correlations were observed between VO_{2max} and mean VO_2 in overall playing periods ($r = 0.673$ for both groups pooled; $P \leq 0.05$), as well as between VO_{2max} and mean PAM in all playing periods ($r = 0.935$ and 0.962 for the female and male groups, respectively; $P \leq 0.05$). Because VO_{2max} was not significantly related to mean PAM when the two groups were pooled ($P > 0.05$), it appears that the relation is somewhat gender specific (Fig. 5). One potential explanation for the gender-specific relation may be that male basketball players require a greater VO_2 than female players for a given exercise intensity as defined by the percent of duration for active movements or PAM. This seems likely since male players probably run and move faster in general

while playing the game than female athletes do. This may be true even at the same PAM level. However, because the time-motion analysis used in this study does not allow quantifying the subject's running speed, further investigation with kinematic analysis is needed to have deeper insights into the relation. Despite the limitation, these results indicate that higher VO_{2max} is associated with more vigorous playing, and hence suggest that enhancement of aerobic capacity may be useful in both female and male basketball.

In conclusion, this study demonstrated greater utilization of aerobic metabolism in playing competitive basketball than previously expected (Ainsworth et al., 2000), with values of VO_2 of 33.4 ± 4.0 and 36.9 ± 2.6 mL/kg/min for females and males, respectively. Furthermore, this study showed fair to strong correlations between player's VO_{2max} and VO_2 during play, as well as between VO_{2max} and percent of duration of active movements during play.

Perspectives

In this study, we proposed a novel approach to quantify physiological demands of actual basketball performance with the use of the portable metabolic measurement system. It was also attempted to integrate time-motion analysis with physiological measurements to provide deeper insights into the physiological demands of the sport. We believe that these approaches can be used to examine physiological demands of other athletic events (Berg et al., 2007).

The relatively high level of aerobic demand despite the relatively high percent of playing time ($\sim 66\%$) spent in walking and standing suggests that the role of aerobic metabolism is critical in restoration of phosphocreatine in the sport characterized by high-intensity intermittent play. Fair to strong correlations between VO_{2max} and oxygen uptake during game play and between VO_{2max} and exercise intensity also suggest that aerobic conditioning may be of value in basketball. These findings may be beneficial for coaches and other professionals in the field of basketball to develop training programs which effectively enhance sport-specific fitness (McInnes et al., 1995; Taylor, 2003, 2004). Further work is needed to determine if specific aerobic conditioning improves game performance.

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