The Physical and Physiological Demands of Basketball Training and Competition

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Purpose: To characterize the physical and physiological responses during different basketball practice drills and games. Methods: Male basketball players (n = 11; 19.1 ± 2.1 y, 1.91 ± 0.09 m, 87.9 ± 15.1 kg; mean ± SD) completed offensive and defensive practice drills, half court 5on5 scrimmage play, and competitive games. Heart rate, $V_{O_2}$ and triaxial accelerometer data (physical demand) were normalized for individual participation time. Data were log-transformed and differences between drills and games standardized for interpretation of magnitudes and reported with the effect size (ES) statistic. Results: There was no substantial difference in the physical or physiological variables between offensive and defensive drills; physical load (9.5%; 90% confidence limits ±45); mean heart rate (–2.4%; ±4.2); peak heart rate (–0.9%; ±3.4); and $V_{O_2}$ (–5.7%; ±9.1). Physical load was moderately greater in game play compared with a 5on5 scrimmage (85.2%; ±40.5); with a higher mean heart rate (12.4%; ±5.4). The oxygen demand for live play was substantially larger than 5on5 (30.6%; ±15.6). Conclusions: Defensive and offensive drills during basketball practice have similar physiological responses and physical demand. Live play is substantially more demanding than a 5on5 scrimmage in both physical and physiological attributes. Accelerometers and predicted oxygen cost from heart rate monitoring systems are useful for differentiating the practice and competition demands of basketball.

Keywords: accelerometry, heart rate, team sport, workload

The development of wearable, miniaturized smart sensor devices has provided new avenues of research in the sport sciences, including investigating the demands of team sports. The use of smart sensor devices in basketball may provide important information about the physical and physiological demands during practice and competition. Although the movement characteristics of basketball competition have been documented in a small number of time-motion studies,1-3 little is...
known regarding the physical demand, with respect to whole body movement, or the associated physiological response to offensive and defensive drills, and gameplay. Consequently, how these responses contribute to, and impact on the overall practice and/or competition exercise is not well understood.

Time motion analysis shows that players may cover several kilometers during a basketball game, comprising many high speed movements in forward and lateral directions combined with decelerations from frequent sprint efforts. Explosive vertical jumps may be executed up to 50 times per game. Heart rate and blood lactate concentration have been the main focus of investigations into physiological demands. Competition for elite males may elicit maximal heart rate values up to 190 beats·min\(^{-1}\). More recently, mean heart rates of 171 beats·min\(^{-1}\) or 91% of the maximal heart rate have been recorded during play. Measures of blood lactate concentration indicate that anaerobic metabolism makes a substantial contribution to the supply of energy for muscular contraction. Mean values for male basketball players have been recorded at 8.5 ± 3.1 mmol·L\(^{-1}\) and 5.7 ± 2.1 mmol·L\(^{-1}\) during international-level female games. However, blood lactate is only a surrogate indicator of anaerobic metabolism, as concentrations may be ≈1/3 of the muscle concentration, and are influenced by the exercise intensity immediately before sample collection. Heart rate may be a limited indicator of aerobic metabolism during basketball due to rapid movements of upper body segments, cardiovascular drift, or an altered autonomic tone. Despite preliminary efforts to describe some of the physiological aspects of basketball play, the aerobic (V\(_{\text{O}_2}\)) energy demands of competition are unknown.

Recently, the development of personal heart rate telemetry systems incorporating predictive software can provide real-time estimates of the V\(_{\text{O}_2}\) during training and competition. These systems offer great flexibility for team sport practitioners as multiple players can be monitored, and their heart rate and V\(_{\text{O}_2}\) responses viewed in real time. This methodology offers coaches and support staff the opportunity to modify the intensity (or duration) of a practice session if objectives are not being met. Competition intensity can also be quantified, allowing practice drills of similar intensity to be designed. The Suunto system has shown to be reliable, with a typical error of 0.64 mL·kg\(^{-1}\)·min\(^{-1}\) (≈1.5%) and a coefficient of variation of (6%). This degree of reliability (accuracy) is sufficient in characterizing moderate to larger changes or differences in aerobic capacity (>6%) but not small subtle changes.

Triaxial accelerometers are now available which are relatively unobtrusive for use during team sport training and competition. Accelerometers have been used extensively in the general population as a measure of physical activity level. The physical demands of team sports have been evaluated using Global Positioning System (GPS) technology. GPS may be appropriate in outdoor settings which allow satellite reception, but is unusable for indoor sports such as basketball. To our knowledge, only one study has been conducted in basketball and other high intensity team sports that quantified the physical demands by using accelerometer technology. Accelerometers were used in boy’s basketball with moderate correlations between accelerometer output and heart rate. The authors concluded that accelerometers were sensitive enough to quantify the physical demands and the intensity level during a typical basketball session. However, the accelerometer used in that study was a uniaxial version, and possibly underestimated the true physical demands as only one plane of movement was measured. To gain further insight
into the demands of basketball using accelerometer technology, player movement should be measured in all three planes (triaxial accelerometry). Many offensive and defensive basketball movements are combinations of forward, backward and/or lateral movements. These rapid movements presumably combine to elicit a substantial physical demand, and associated physiological responses. Given that previous time motion observations predominantly focused on running, the aim of this study was to quantify differences in whole body dynamics (physical demand), heart rate and predicted VO$_2$ responses (physiological demand) between selected offensive and defensive practice drills, reduced court area competition (5on5 scrimmage), and live game play.

**Subjects**

Eleven elite junior male players (age 19.1 ± 2.1 y, height 1.91 ± 0.09 m, mass 87.9 ± 15.1 kg, measured maximal heart rate 201 ± 4 beats·min$^{-1}$, estimated peak VO$_{2\text{max}}$ 68.6 ± 1.3 mL·kg$^{-1}$·min$^{-1}$, Σ7 skinfold 68.9 ± 32.1 mm; mean ± SD) volunteered to participate in the investigation. The study was approved by the Ethics Committee of the Australian Institute of Sport (Approval Number 20060803), and all players were verbally informed of the study requirements, and provided written informed consent before commencement.

**Design**

To assess the demands of competition, players competed in three full competition games in 3 d (one game per day) against different teams. Each player was fitted with a commercially available heart rate monitoring device (Suunto Pro Team Pack, Vantaa, Finland), and a triaxial accelerometer (MiniMaxX, Catapult Innovations, Melbourne, Australia) located at the lumbosacral region, held secure against the body in an elastic pouch fixed to the inside of Lycra under shorts. Pilot testing revealed this position provided the best indication of whole body movement, as the location is close to a player’s center of mass. To assess the demands of practice, 9 of the 11 players completed unstructured offensive and defensive practice drills as directed by the coach, and reduced court 5on5 scrimmage competition on seven separate occasions over 2 wk, using the heart rate and accelerometer systems. A total of 190 defensive, 57 offensive, and 48 5on5 scrimmage drills were evaluated in practice and 128 on-court periods during competition games. The nature of the practice drills varied slightly in design characteristics, but had the same strategic offensive or defensive focus and movement patterns. The 5on5 scrimmage is a commonly used training (typically half-court) method to imitate competition, and practice strategic plays at game intensity. Comparisons of the accelerometer data, heart rate response and estimated VO$_2$ were made between the offensive and defensive drills, the 5on5 scrimmage and live competition games.

**Methodology**

To validate the whole body movement characteristics captured by the accelerometer, we conducted a controlled validation trial of a defensive movement drill (“close outs”). We used this trial given its movement patterns formed the basis of many of
the drills performed during the practice sessions. We employed a construct validity approach to determine if there were substantial differences in outputs derived from the accelerometer data across several trials of the same movement patterns. This type of validity relates to basketball attributes (constructs) which cannot easily be measured (eg, nonquantifiable actions such as multisegmental movement). We hypothesized that if there were trivial differences between the validity trials, then we could be confident that (dis)similarities in the physical demands between offensive and defensive drills would be represented accordingly.

The trial required players to perform the same close-out movement pattern (within a 5 × 5 m grid) at maximal intensity in both left and right directions, in random order. In total, players completed 12 trials, 6 with and 6 without an opponent. All heart rate and accelerometer data during the validation trials, practice and competition periods was normalized for actual playing time; that is, only the data related to actual live play or live drill time was processed using LoganPlus v4 (Catapult Innovations, Melbourne, Australia). All variables for each player were divided by the drill duration providing normalized outcomes independent of time.

The whole body movements of practice and competition were expressed as the accumulated load. This estimate of physical demand combines the instantaneous rate of change in acceleration in three planes of body movement: up/down (z), side/side (y) and forward/backward (x) according to the formula:

\[
Load = \sqrt{(Ac_1n - Ac_{1n-1})^2 + (Ac_{2n} - Ac_{2n-1})^2 + (Ac_{3n} - Ac_{3n-1})^2}
\]

where \(Ac_1\), \(Ac_2\) and \(Ac_3\) are the orthogonal components of acceleration measured from the triaxial accelerometer directions at 100 Hz. To reduce the value for ease of use, the resultant was multiplied by a scaling factor of 0.01, so it is representative of a 1/100-s summation. These values are then accumulated over the length of the drill to obtain the total physical demand. This unit of quantification, reported here in arbitrary units (a.u.) has some advantages over using other metrics of effort, such as distance or velocity, as the calculation accumulates whole body movements (ie, the demand of moving the center of mass around the court). Unpublished observations during our pilot trials indicated that the accumulated load was highly correlated to heart rate and blood lactate accumulation during 1on1 drills, and 2on2 scrimmage play.

Peak heart rate (HR\(_{\text{peak}}\)) for each player was determined by completing the YoYo intermittent recovery test\(^{21}\) using the Suunto system. Heart rate measures during the practice sessions were then expressed as a percentage of this HR\(_{\text{peak}}\), and the mean heart rate during the practice or game period.

All players had their estimated peak \(V_\text{O}_2\) determined during the YoYo intermittent recovery test while using the Suunto system. Predictions of \(V_\text{O}_2\) were determined within the Suunto software. The analysis required the specification of the participant’s basic personal information of age, mass, height, gender and level of activity. The software then provided a predicted maximal oxygen capacity. Individual HR\(_{\text{peak}}\) as determined from the YoYo test was added to this information for each player’s profile to improve the predicted accuracy of the \(V_\text{O}_2\) measures. Although the predicted value may be \(\approx 2.7\ \text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}\) below the true value when compared with a calibrated metabolic cart,\(^{22}\) the addition of HR\(_{\text{peak}}\) improves the accuracy by 7%.\(^{15}\) Based on our previous research\(^{15}\) which estimated the typical
error of measurement as 1.8%, and the smallest worthwhile difference in VO₂ as ≈ 2.3 mL·kg⁻¹·min⁻¹ (calculated as 0.2 × between-subject SD), we were confident that any practical/clinically meaningful (significant) differences in the VO₂ between practice drills, or play conditions would be identified.

Mean peak heart rate was derived from each player’s peak heart rate during a practice session participating in an offensive, defensive and 5on5 drills, or within a game period. Similarly, mean heart rate was determined from each player’s average heart rate within each drill or game period. Perceived intensity during drills and competition was assessed by using a modified CR10 scale.23

Statistical Analysis

Differences in the means for defensive and offensive drills, 5on5 scrimmage and live play conditions were compared using log-transformed data as per methods outlined previously.24 Precision of estimates were indicated with 90% confidence limits, which defines the range representing the uncertainty in the true (unknown) value of the population mean. Magnitude-based inferences on the differences between conditions were made by standardizing differences using the between-subject standard deviation. A difference was classified as substantial where there was a ≥75% likelihood that the mean effect was greater than or equal to a small ES (±0.2). An effect was inferred to be unclear if its confidence interval spanned substantial positive and substantial negative values. Qualitative magnitudes of standardized effects were assessed using the following descriptive scale: trivial < 0.2, small 0.2 to 0.6, moderate 0.6 to 1.2, large 1.2 to 2.0 and very large >2.0.25

Results

Descriptive statistics (mean ± SD) for the raw values of accelerometer and physiological variables measured are shown in Table 1. The mean (± SD) duration of offensive and defensive drills were 5:28 ± 1:51 and 4:29 ± 1:41 min:s.

When normalized for time there were only trivial differences between the validation trial, defense and offense drills for the majority of variables. There was no clear difference in physical demand between offensive and defensive drills (Figure 1), or mean and HR_peak (Table 2). There was a moderate but substantially greater VO₂ requirement (6% difference; ≈ 2.9 mL·kg⁻¹·min⁻¹) for defensive compared with offensive drills (Figure 2).

Mean duration for 5on5 drills, and the isolated periods of live play were 8:37 ± 4:56 and 9:30 ± 3:26 min:s respectively. The physical demand of live play is substantially more demanding than 5on5 or offensive and defensive drills (Figure 1). VO₂ (31% difference; ≈ 5.4 mL·kg⁻¹·min⁻¹; Figure 2), mean heart rate and HR_peak are substantially more intense during live play than a 5on5 scrimmage (Table 2).

Discussion

Within the team sport environment, estimations of physical and physiological demand are often limited by the cost and effectiveness of the available technology. Cost effective wearable sensor technology permits more systematic monitoring of the physical demands and physiological responses during training and competition.
Table 1  Raw values (mean ± SD) for accumulated load (Acc load), peak and mean heart rate (HR), oxygen use ($V_{O2}$) and the rate of perceived exertion (RPE) during various forms of basketball practice and competition

<table>
<thead>
<tr>
<th>Drill</th>
<th>Acc load (a.u./min)</th>
<th>Peak HR (beats • min$^{-1}$)</th>
<th>Mean HR (beats • min$^{-1}$)</th>
<th>$V_{O2}$ (mL • kg$^{-1}$ • min$^{-1}$)</th>
<th>$V_{O2}$ (%)</th>
<th>Mean RPE (1–10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation trial</td>
<td>62 ± 10</td>
<td>166 ± 14</td>
<td>147 ± 15</td>
<td>42.9 ± 5.5</td>
<td>62 ± 1</td>
<td>7</td>
</tr>
<tr>
<td>Defense</td>
<td>58 ± 26</td>
<td>170 ± 7</td>
<td>152 ± 7</td>
<td>45.1 ± 3.6</td>
<td>66 ± 5</td>
<td>7</td>
</tr>
<tr>
<td>Offense</td>
<td>55 ± 15</td>
<td>165 ± 6</td>
<td>147 ± 5</td>
<td>42.3 ± 3.0</td>
<td>63 ± 6</td>
<td>7</td>
</tr>
<tr>
<td>5on5</td>
<td>171 ± 84</td>
<td>171 ± 12</td>
<td>147 ± 10</td>
<td>40.2 ± 7.1</td>
<td>59 ± 10</td>
<td>9</td>
</tr>
<tr>
<td>Game</td>
<td>279 ± 58</td>
<td>173 ± 6</td>
<td>162 ± 7</td>
<td>51.2 ± 3.4</td>
<td>70 ± 16</td>
<td>7</td>
</tr>
</tbody>
</table>

Note. $%V_{O2}$ refers to a percentage of the peak value achieved during the YoYo test.
Table 2 Differences in the estimates of physical and physiological demands between defensive and offensive drills, and 5on5 and live competition

<table>
<thead>
<tr>
<th>Difference Between Defense and Offense</th>
<th>% Difference (90% CL)</th>
<th>Effect size (±90% CL) Descriptor</th>
<th>% Difference (90% CL)</th>
<th>Effect size (±90% CL) Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated load</td>
<td>10 (–25 to 59)</td>
<td>0.26 (±1.08) Unclear</td>
<td>85 (32 to 160)</td>
<td>1.17 (±0.65) Moderate</td>
</tr>
<tr>
<td>Peak heart rate</td>
<td>–1 (–4 to 3)</td>
<td>–0.20 (±0.77) Unclear</td>
<td>3 (–2 to 8)</td>
<td>0.43 (±0.76) Unclear</td>
</tr>
<tr>
<td>Mean heart rate</td>
<td>–2 (–6 to 2)</td>
<td>–0.51 (±0.88) Unclear</td>
<td>12 (7 to 18)</td>
<td>1.70 (±0.77) Large</td>
</tr>
<tr>
<td>Mean estimated $V_{O2}$</td>
<td>–6 (–13 to 3)</td>
<td>–0.69 (±1.02) Unclear</td>
<td>30 (13 to 51)</td>
<td>1.47 (±0.80) Large</td>
</tr>
</tbody>
</table>

Note. Comparisons between conditions are shown as a percentage (90% confidence limit [CL]). The magnitude of difference between conditions was assessed with the following criteria: trivial < 0.2, small 0.2–0.6, moderate 0.6–1.2, large 1.2–2.0 and very large > 2.0. A difference was classified as substantial where there was a ≥75% likelihood that the mean effect was greater than or equal to a small ES (±0.2). An effect was inferred to be unclear if its confidence interval spanned substantial positive and substantial negative values. Negative values represent lower demand.
Figure 1 — The accumulated physical load for basketball practice drills and competition as determined by triaxial accelerometry after being normalized for time in each condition. Values are arbitrary units (a.u.). Error bars show the SD. Moderate difference between 5on5 and live play; ES, 1.17 (±0.65). #Indicates substantial difference to all drills.

Figure 2 — Oxygen demand values during practice and competition expressed as a percentage of predicted $V_{\text{O}_2}$ (a), and the peak values during each drill or live play (b). Error bars show the SD. Large difference were evident between live play and 5on5; ES, 1.97 (±0.62). *These are greater than the smallest clinical difference ($\approx 3$ mL·kg$^{-1}$·min$^{-1}$) for predicted $V_{\text{O}_2}$. 
Time motion analysis and heart rate were traditional criterion methods to assess and understand physical demands, and intensity in team sports. We have shown that the combination of heart rate, accelerometry, and heart rate-predicted $V_{\text{O}_2}$ information can be used to differentiate the physical and physiological demands during certain aspects of basketball practice and competition.

During basketball practice, players will experience similar physical demands and physiological responses to the execution of offensive or defensive drills. Coaches are often concerned with the amount of training that occurs during the week, and the implication this volume may have on subsequent performance. Recognizing that the main conditioning component may be the competition itself, basketball coaches can now have a deeper understanding that weekly practice sessions can focus on the tactical offensive and defensive components of team play and rely on the competition, which may comprise several games in as many days, to maintain player condition. Astute coaches will periodize the training schedule to accommodate the demands of weekly competition. Recognizing that multiple games will increase physical and physiological demands and reduce subsequent performance, and recovery of players, initial practice sessions of the following week may need to be of lower intensity. Coaches armed with information regarding the intensity and demands of drills can structure lighter sessions early in the week, and develop more demanding 5on5 type scrimmage drills later in the week as playing-related soreness decreases.

Competitive live games have substantially greater physical and physiological demands compared with a 5on5 scrimmage play. The higher demands of a live game are likely a consequence of the players competing over the whole court, rather than half-court in the 5on5 scrimmage. However the contribution from the individual planar axes needs to be quantified to determine where the majority of movement is accumulated during game exercise. Intuitively, the forward/backward contribution from the additional running up and down the court during transition creates an increased physical load, and physiological response. Similarly, there may also be increased movement intensity during offensive evasive, and defensive reactive movements, which may also contribute to an increase in physical demand.

The similarity in peak heart rates indicates that peak intensity during a 5on5 scrimmage is comparable to that of live game play; essentially, players are reaching the same intensity during both games and scrimmages. However, the overall intensity is lower as reflected in the large difference in mean heart rate between 5on5 and live play; this may be an artifact of players not sustaining the same workloads at, or close to peak intensity for the same volume of time as in actual game play. In addition, there may have been more stoppages during the 5on5 for coaching instruction. These differences appear sufficient enough to allow the heart rate to recover slightly eliciting a lower level. These outcomes highlight the utility of the Suunto system for identifying and comparing differing responses between practice and competition.

With particular reference to basketball, it should be noted that there may be limitations with the use of heart rate-predicted oxygen demands. Basketball game activities often require players to exert force in isolated or combined dynamic and isometric actions. These activities such as screening, blocking or positioning for rebounds and court position involve muscle recruitment from both the upper and
lower body. In these circumstances, where whole body movement demand is not high, the heart rate may be elevated and therefore predictions of oxygen demand may be inaccurate. It has been shown that when muscles act statically in straining type exercise that heart rate can be higher than dynamic leg exercise. Therefore, oxygen demand may be overestimated when heart rate remains high despite lower whole body activity.

It appears that 5on5 scrimmage is an efficient form of skill and tactical practice, without excessive increases in physical and/or physiological demand. This form of training can be used to a much greater extent without increasing lower limb stress and the overall training load. Our data confirms the custom of using half-court practice drills and games is an effective means of limiting the high physiological demands of full court practice on a daily basis. Although there will be a substantial aerobic demand when players perform 5on5 scrimmage, coaches should be aware that this type of practice is not as intensive as full competition play. Other more intensive conditioning drills and training methods will need to be employed to develop game-specific fitness.

**Practical Applications**

In summary, accelerometer technology combined with predicted values of oxygen demand is a useful tool to determine the demands of basketball. This information can provide critical insight for the development and monitoring of training. During team practice, offensive and defensive drills have similar physical and physiological demands, leading to similar conditioning outcomes while having different tactical foci. Coaches should be aware that the physical demands of a 5on5 scrimmage are substantially lower than live game play, although the structural/tactical benefits should not be underestimated. Further investigation using accelerometer technology is needed to characterize the individual contribution of each orthogonal plane to the overall physical demand during live play.

**Conclusions**

The use of wearable sensor technology is useful for quantifying the physical and physiological demands of basketball practice and competition, inasmuch as offensive and defensive basketball drills obtain similar physical and physiological demands during routine practice sessions. Reduced area (half-court) drills such as a 5on5 scrimmage elicit lower physical and/or physiological demands than live play, and should therefore be used to develop tactical elements of play rather than fitness conditioning per se.

**Acknowledgments**

We thank the coaching and playing staff from the Australian Institute of Sport Men’s Basketball program for their participation in the study. Grateful thanks also to the staff from the Department of Physiology, Australian Institute of Sport, for their technical assistance. This study was funded by the Australian Institute of Sport, Discretionary Research Fund Project No. 995072. The results of the current study do not constitute endorsement of the products by the authors or the journal.
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