Development of the Basketball Exercise Simulation Test (BEST) based on the activity demands of current open-age Australian male competition

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Declaration

Except where due acknowledgement has been made, the work is that of the candidate. The thesis topic and experimental designs were developed with the assistance of Associate Professor Peter Reaburn and Dr Ben Dascombe (candidate’s supervisors), and Mr Greg Capern (laboratory technician). The work has not been submitted previously, in whole or in part, to qualify for any other academic award. The content of the thesis is the result of work carried out since the official starting date of the program.

______________________________

Aaron Terrence Scanlan (Candidate)
Publications Arising From Thesis


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Dedication

To my Nana and Pop, Alice and John, you were the best grandparents anyone could ever hope to have. You were two of the most caring, open-hearted people who certainly had my utmost admiration and respect. Losing you during the last four years was incredibly tough for many of us. However, you were able to impact so many lives and teach us more than you ever knew during your time here. Most importantly of which, was the love that you had for each other and your family, which will stay with us for many years to come. You will both forever be in my thoughts.
Basketball is a court-based team sport consisting of competitive matches lasting between 40-48 min. Basketball teams generally consist of 10-12 players, with five players being on-court at any one time and frequent substitutions being made. The five on-court playing positions include point guard, shooting guard, small forward, power forward, and centre. Due to the relatively small playing area of a basketball court (~28 m x 15 m), players perform repeated accelerations and decelerations, with frequent changes in direction during match play. As such, basketball competition is highly intermittent, with substantial contributions from the alactic, lactic, and oxidative energy systems. Subsequently, basketball performance has been suggested to impose unique metabolic demands upon players. Recently, an increasing number of researchers have attempted to quantify these demands through the analysis of player movements during basketball competition.

Historically, video-based time-motion analysis (TMA) procedures have been used to determine the activity requirements of basketball competition. However, this technology has not been used to analyse the activity demands of current Australian male basketball competition. Furthermore, no research has compared the match playing demands between competition levels in open-age male basketball. Without such data, the development of field or laboratory tests simulating actual match activity demands is not permissible. Considering tests replicating the requirements of competition have been suggested to offer the greatest practical benefit in team sports, the development of such a test specific to basketball match activity is warranted.

Therefore, the present thesis firstly aimed to describe and compare the player activity demands within elite and sub-elite open-age Australian male basketball competitions; and secondly develop a reliable and valid basketball simulation test based on these demands. These aims were addressed within four sequential research studies.
Study One: A comparison between the activity demands of elite and sub-elite open age Australian male basketball competitions

The activity demands of elite and sub-elite open-age Australian male basketball competitions were described and compared within Study One. The activity demands of elite (n = 10; age: 28.3 ± 4.9 yr; stature: 197.4 ± 8.3 cm; body mass: 97.0 ± 13.9 kg) and sub-elite (n = 12; 26.1 ± 5.3 yr; 85.9 ± 13.2 kg; 191.4 ± 7.6 cm) Australian male basketball players were measured across multiple (elite: n = 2; sub-elite: n = 3) competitive matches. Video-based time-motion analysis (TMA) methodology was used to determine the frequency, mean and total duration (s), and mean and total distance (m) data for standing/walking, jogging, running, sprinting, low shuffling, high shuffling, and dribbling activity. Only frequencies were determined for jumping and upper-body movements. All activity data were further analysed according to backcourt (BC) (guards) and frontcourt (FC) (forwards and centres) playing positions. Elite players experienced significantly more total movement changes (2743 ± 133 vs. 1972 ± 175, p < 0.05), and performed greater jogging (2184 ± 34 m vs. 1786 ± 70 m, p < 0.01) and running workloads (2989 ± 42 m vs. 2040 ± 81 m, p < 0.001) than sub-elite players. Further, sub-elite players spent significantly (p < 0.01) more time standing/walking (765 ± 18 s vs. 1080 ± 65 s) and sprinting (11 ± 2 s vs. 120 ± 20 s) than elite players. In conclusion, these results suggest elite open-age Australian male basketball players work more consistently at or above moderate movement intensities and demonstrate a more intermittent work profile than sub-elite players during match play.
Study Two: The intra-match activity variation during elite and sub-elite open-age Australian male basketball competitions

The intra-match activity variation during current open-age Australian male basketball competition was analysed in Study Two through further analysis of the data collected in Study One. Movement frequencies, total durations (s), total distances (m), and mean velocities (m∙s⁻¹) were calculated for low-intensity (LIA) (standing/walking and jogging), high-intensity (HIA) (running and sprinting), shuffling, and dribbling activity, with only movement frequencies determined for jumping and upper-body activity. Stoppage time (s) was also calculated across each quarter for each playing level. Large-very large declines (11-17%, effect size (ES) = 1.2-3.1) in HIA were evident for elite players during the latter quarters of matches. In opposition, sub-elite players experienced small increases (1-5%, ES = 0.1-0.3) in HIA across the last quarter of matches. The observed intra-match HIA variation within elite competition may be attributed to strategic play. Elite players travelled at significantly (p < 0.05) lower dribbling (Quarter (Q) 1: 3.09 ± 0.03 m∙s⁻¹; Q3: 2.81 ± 0.01 m∙s⁻¹) and total activity velocities (Q1: 2.22 ± 0.04 m∙s⁻¹; Q3: 2.09 ± 0.03 m∙s⁻¹) during the third quarter of play when compared to the first quarter. This may indicate an attempt to increase offensive control and slow the speed of the match towards the end of competition. Conversely, the moderate-large increases in stoppage duration across the second (24%, ES = 0.7) and fourth quarters (60%, ES = 1.5) compared to the first and third quarters during sub-elite competition may explain the reduced variation in intra-match activity intensity within these players. The increased recovery durations might have allowed enhanced maintenance of HIA output during competition, which is supported by a significant large correlation (r = 0.614, p = 0.034) between stoppage time and mean HIA velocity for sub-elite players across match quarters. In summary, it appears that the activity demands of open-age Australian basketball competition vary across playing periods. Specifically, greater declines in overall activity intensity were evident across the latter playing periods in the elite competition compared to sub-elite match play.
Study Three: The Basketball Exercise Simulation Test (BEST): A match-specific physical fitness test for basketball players

The purpose of Study Three was to develop a reliable and valid field test that simulates the match activity demands of elite open-age Australian male basketball competition. Open-age Australian male basketball players (n = 15; age: 22.1 ± 6.6 yr; stature: 187.2 ± 8.2 cm; body mass: 89.4 ± 11.0 kg; body fat: 20.0 ± 6.6%) from state- and regional-level competitions participated in the study. The activity data from Studies One and Two were used to construct a field-based circuit test representative of basketball match activity requirements. The Basketball Exercise Simulation Test (BEST) circuit design was developed within one half of a regulation International Basketball Federation (FIBA) basketball court. Each circuit consisted of 30 s of activity, and was continuously repeated for 12 min to simulate the playing time for a quarter of live basketball competition. All participants (n = 15) completed one trial of a repeat-sprint protocol and the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) as criterion tests for anaerobic and aerobic fitness. A trial of the BEST was then completed by all participants within 7 days. Separately, nine participants completed another trial of the BEST 7 days later. Multiple measurements were collected during the BEST, including mean heart rate (HR) (b∙min⁻¹), sprint decrement (%), mean sprint and circuit time (s), and total distance covered (m). Test-retest reliability was determined by calculating the Intra-class Correlation Coefficient (ICC), Typical Error of Measurement, Coefficient of Variation (CV), and 95% Confidence Intervals across the two BEST trials. The BEST possessed adequate reliability evidenced by strong ICC values for mean sprint (ICC = 0.99) and circuit time (ICC = 0.98), and sprint decrement (ICC = 0.93). Acceptable reliability was also observed for the BEST through mean circuit time (CV = 1.4%), total distance (CV = 1.5%), and mean sprint time measures (CV = 1.7%). Additionally, the BEST displayed suitable criterion validity with significant (p < 0.001) relationships evident between mean sprint and circuit time, and sprint decrement during the BEST and repeat-sprint performance (r = 0.81-0.92), as well as Yo-Yo IR1 distance (r = -0.71-0.85). It was concluded that the BEST is a reliable and valid match-specific assessment tool for determining basketball-related anaerobic and aerobic fitness.
Study Four: The construct and longitudinal validity of the Basketball Exercise Simulation Test (BEST)

The construct and longitudinal validity of the BEST was determined in Study Four. State-level (n = 10; age: 22.7 ± 6.1 yr; stature: 189.6 ± 9.5 cm; body mass: 86.5 ± 18.7 kg; body fat: 14.7 ± 3.5%) and regional-level (n = 10; 26.6 ± 4.0 yr; 185.9 ± 7.9 cm; 92.6 ± 8.4 kg; 23.8 ± 6.3%) Australian male basketball players completed a Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) and 12-min trial of the BEST during the middle of a competitive season. Eight participants (state: n = 4; regional: n = 4) completed a further Yo-Yo IR1 and trial of the BEST towards the end of the season. To determine the construct validity of the BEST, differences in repeat-sprint, Yo-Yo IR1, and BEST performance were assessed between playing levels. The longitudinal validity of the BEST was established through relationships between changes (%) in repeat-sprint as well as Yo-Yo IR1 performance and BEST performance across an 8-week period during the season. The BEST displayed adequate construct validity with state-level players observed to significantly (p < 0.01) outperform region-level players in repeat-sprint time (54.4 ± 8.3 s vs. 63.1 ± 21.5 s, p < 0.001), Yo-Yo IR1 distance (1283 ± 62 m vs. 636 ± 297 m, p < 0.01), and all BEST performance measures including mean sprint time (1.45 ± 0.01 s vs. 1.65 ± 0.03 s, p < 0.01), mean circuit time (18.98 ± 1.79 s vs. 22.72 ± 2.01 s, p < 0.001), and sprint decrement (8.54 ± 0.15% vs. 15.38 ± 0.27%, p < 0.01). Additionally, the BEST possessed acceptable longitudinal validity evidenced through a significant very large negative relationship (r = -0.815, p < 0.05) between the changes in Yo-Yo IR1 performance and BEST sprint decrement across the playing season. In addition, large-very large correlations were observed between longitudinal changes in repeat-sprint performance and BEST sprint decrement (r = 0.581), and Yo-Yo IR1 performance and BEST circuit time (r = -0.705). In summary, the BEST was supported as a valid match-specific assessment tool for discriminating and evaluating basketball-related anaerobic and aerobic fitness, with sprint decrement appearing to be the most valid measure.
In summary, the present thesis provides the first known match activity analysis for current Australian and open-age male basketball players. Furthermore, comparisons in match activity demands were made between competition levels. Elite players were observed to work more consistently at or above moderate activity intensities and experience a more intermittent work profile across matches than sub-elite players. Moreover, larger declines in activity intensity with match progression were evident during elite competition compared with sub-elite competition, possibly due to tactical strategies and match constraints. The activity data from these analyses were used to develop the first field test specific to the activity requirements of current elite basketball competition, the Basketball Exercise Simulation Test (BEST). The reliability, as well as the criterion, construct, and longitudinal validity of the BEST were shown to be acceptable, demonstrating that the BEST can be used to assess and discriminate basketball-related anaerobic and aerobic fitness across different playing levels. The present findings offer a significant contribution to the existing understanding of Australian and open-age male basketball competition demands. Furthermore, the development of the BEST allows match-specific demands to be replicated within controlled environments, and thus may offer several benefits to basketball coaches, players, conditioning staff, and researchers.
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<th>Description</th>
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<tbody>
<tr>
<td>AnT</td>
<td>Anaerobic threshold</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine triphosphate</td>
</tr>
<tr>
<td>b·min⁻¹</td>
<td>Beats per minute</td>
</tr>
<tr>
<td>BC</td>
<td>Backcourt</td>
</tr>
<tr>
<td>BEST</td>
<td>Basketball Exercise Simulation Test</td>
</tr>
<tr>
<td>%BF</td>
<td>Percent body fat</td>
</tr>
<tr>
<td>BLa⁻</td>
<td>Blood lactate</td>
</tr>
<tr>
<td>[BLa⁻]</td>
<td>Blood lactate concentration</td>
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<tr>
<td>°C</td>
<td>Degrees Celsius</td>
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<td>C</td>
<td>Centre playing position</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<td>Countermovement jump</td>
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<td>Centimetre</td>
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<td>Elite frontcourt</td>
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<td>Forward playing position</td>
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<td>FIBA</td>
<td>International Basketball Federation</td>
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<td>G</td>
<td>Guard playing position</td>
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<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>h</td>
<td>Hour</td>
</tr>
<tr>
<td>HIA</td>
<td>High-intensity activity</td>
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<tr>
<td>High Sp</td>
<td>High-intensity specific movements</td>
</tr>
<tr>
<td>HR</td>
<td>Heart rate</td>
</tr>
<tr>
<td>%HR&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Relative heart rate</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>ICC</td>
<td>Intra-class Correlation Coefficient</td>
</tr>
<tr>
<td>Int</td>
<td>International</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
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<tr>
<td>km</td>
<td>Kilometre</td>
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<tr>
<td>La-</td>
<td>Lactate</td>
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<tr>
<td>[La-]</td>
<td>Lactate concentration</td>
</tr>
<tr>
<td>LIA</td>
<td>Low-intensity activity</td>
</tr>
<tr>
<td>Low Sp</td>
<td>Low-intensity specific movements</td>
</tr>
<tr>
<td>m</td>
<td>Metre</td>
</tr>
<tr>
<td>m∙s⁻¹</td>
<td>Metres per second</td>
</tr>
<tr>
<td>MANOVA</td>
<td>Multiple Analysis of Variance</td>
</tr>
<tr>
<td>Med Sp</td>
<td>Medium-intensity specific movements</td>
</tr>
<tr>
<td>MIA</td>
<td>Moderate-intensity activity</td>
</tr>
<tr>
<td>min</td>
<td>Minute</td>
</tr>
<tr>
<td>ml∙kg⁻¹∙min⁻¹</td>
<td>Millilitres of oxygen consumed per kilogram per minute</td>
</tr>
<tr>
<td>mmHg</td>
<td>Millimetres of mercury</td>
</tr>
<tr>
<td>mmol∙L⁻¹</td>
<td>Millimoles per litre</td>
</tr>
<tr>
<td>MP</td>
<td>Mean power</td>
</tr>
<tr>
<td>N/A</td>
<td>Not available</td>
</tr>
<tr>
<td>n</td>
<td>Sample size</td>
</tr>
<tr>
<td>Nat</td>
<td>National</td>
</tr>
<tr>
<td>NBA</td>
<td>National Basketball Association</td>
</tr>
<tr>
<td>NBL</td>
<td>National Basketball League</td>
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<tr>
<td>O₂</td>
<td>Oxygen</td>
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<td>Alpha</td>
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<td>PCr</td>
<td>Phosphocreatine</td>
</tr>
<tr>
<td>PO</td>
<td>Power output</td>
</tr>
<tr>
<td>PP</td>
<td>Peak power</td>
</tr>
<tr>
<td>Q</td>
<td>Quarter</td>
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QBL  Queensland Basketball League
r  Pearson Product Moment Correlation Coefficient
rPARQ  Revised Physical Activity Readiness Questionnaire
s  Second
SD  Standard deviation
SEBC  Sub-elite backcourt
SEFC  Sub-elite frontcourt
SJ  Squat jump
SPSS  Statistical Package for Social Sciences
%Speed_{\text{max}}  Relative speed
TEM  Absolute Typical Error of Measurement
%TEM  Relative Typical Error of Measurement
TMA  Time-motion analysis
US  United States
VJ  Vertical jump
VJH  Vertical jump height
\dot{\text{VO}}_2  Oxygen consumption
\dot{\text{VO}}_{2\text{max}}  Maximal oxygen consumption
%\dot{\text{VO}}_{2\text{max}}  Relative oxygen consumption
vs.  Versus
VT  Ventilatory threshold
W  Watts
W\cdot\text{kg}^{-1}  Watts per kilogram
Yo-Yo IR1  Yo-Yo Intermittent Recovery level 1 Test
yr  Year
\sum  Sum
Chapter 1

Introduction
1.0 BACKGROUND

Basketball is a court-based team sport played within many countries around the world, including Australia. Basketball competitions range from recreational to elite, with players experiencing extensive intermittent demands during matches (Ben Abdelkrim, Castagna, El Fazaa & El Ati, 2010a; Ben Abdelkrim et al. 2010b; Ben Abdelkrim, El Fazaa & El Ati, 2007; Bishop & Wright, 2006; McInnes, Carlson, Jones & McKenna, 1995; Narazaki, Berg, Stergiou & Chen, 2009). As such, it has been suggested that basketball match activity relies upon mixed contributions from the alactic, lactic, and oxidative energy systems (Ben Abdelkrim et al. 2007; Crisafulli et al. 2002; Hoffman, Epstein, Einbinder & Weinstein, 1999; McInnes et al. 1995). In recent times, an increasing number of researchers have attempted to describe the match demands of basketball in detail, through examining the responses of players across competition. However, despite this growing body of research, the current demands of the sport remain relatively unknown, particularly within Australian and open-age male competition.

To date, most existing research has described the physiology of basketball players during competition, with heart rate (HR) and blood lactate concentration ([BLa\(^\text{-}\)]) the most commonly measured variables (Bean & Merrill, 1994; Ben Abdelkrim et al. 2010a, 2007; Ben Abdelkrim, Castagna, El Fazaa, Tabka & El Ati, 2009; Janeira & Maia, 1998; Matthew & Delextrat, 2009; McArdle, Magel & Kyvallos, 1971; McInnes et al. 1995; Montgomery, Pyne & Minahan, 2010; Narazaki et al. 2009; Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce & Terrados, 2003; Tessitore et al. 2006; Vaquera Jimenez et al. 2008). However, the measurement of these responses only allows assumptions to be made concerning the match demands imposed upon basketball players (Krstrup et al. 2006b; Montgomery et al. 2010). As such, to gather more precise data, an increasing number of studies have utilised time-motion analysis (TMA) methodologies to determine the activity demands of basketball competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Erculj et al. 2008; Janeira & Maia, 1998; Matthew & Delextrat, 2009; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006).
The use of TMA techniques provides detailed data concerning the specific activity loads placed upon players during competition (Dobson & Keogh, 2007). Within basketball, researchers have typically utilised video-based TMA methodologies with various analytical software to measure the match activity demands of players. Despite the increased use of this technology within basketball, existing findings are largely non-applicable to current open-age male competition. This can be attributed to the many limitations evident within these studies, including the examination of match activity requirements across age-restricted (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006) and practice matches (Narazaki et al. 2009; Tessitore et al. 2006), within female athletes (Matthew & Delextrat, 2009; Narazaki et al. 2009), and using non-specific broad movement categories (Bishop & Wright, 2006; Erculj et al. 2008; Narazaki et al. 2009; Tessitore et al. 2006). Furthermore, the only known study to examine the activity demands imposed upon Australian male basketball players analysed pre-season matches following superseded rules and thus the results may not be applicable to current competitive match play (McInnes et al. 1995).

Existing basketball TMA observations are not likely to represent the current match activity demands of open-age male basketball players. This is due to the fact that adult male players have previously been reported to possess superior anthropometric and fitness characteristics to junior and female players, strongly suggesting that their match requirements may differ (Ben Abdelkrim, Chaouachi, Chamari, Chtara & Castagna, 2010c; Carvalho et al. 2011; Delextrat & Cohen, 2009; Greene, McGuine, Leverson & Best, 1998; Lamonte, McKinnex, Quinn, Bainbridge & Eisenman, 1999; Matthew & Delextrat, 2009; Narazaki et al. 2009; Sallet, Perrier, Ferret, Vitelli & Baverel, 2005; Tavino, Bowers & Archer, 1995; Vaquera Jimenez et al. 2008). Moreover, basketball players have been reported to work at lower intensities completing practice activity than during actual competition (Montgomery et al. 2010; Rodriguez-Alonso et al. 2003). Similarly, current basketball match play is suggested to impose greater physical demands upon players than matches played under outdated rules (Cormery, Marcil & Bouvard, 2008). As a result, a new examination of
current activity profiles during open-age male basketball match play is warranted, particularly within Australian competition. This information may benefit basketball through enhancing coaching and conditioning practices related to the sport.

While the investigation of match activity demands within basketball competition may provide useful information, the comparison of these demands between playing levels may offer additional benefit. Previously, match activity comparisons between competition levels have been frequently made within other team sports, with varied activity responses observed (Brewer, Dawson, Heasman, Stewart & Cormack, 2010; Mohr, Krstrup & Bangsbo, 2003; Sirotic, Coutts, Knowles & Catterick, 2009). However, to date only one study has compared basketball match activity demands between playing levels, and these observations were made for junior European players (Ben Abdelkrim et al. 2010a). Therefore, no research has compared player activity demands between different levels of Australian or open-age male basketball competition. Consequently, more research comparing these demands between basketball playing standards is warranted. Such data may assist basketball coaches and support staff through improving player transitioning to higher levels of competition as well as talent identification procedures within the sport.

With the precise current match activity demands of open-age male basketball competition remaining to be accurately described, the controlled assessment of basketball-related fitness using match-specific test protocols has proven difficult. To date, basketball-related fitness has largely been assessed using field tests based on skill-oriented activity and generic fitness parameters (Barfield, Johnson, Russo & Cobler, 2007; Carvalho et al. 2011; Castagna, Chaouachi, Rampinini, Chamari & Impellizzeri, 2009; Castagna, Impellizzeri, Rampinini, D'Ottavio & Manzi, 2008b; Castagna et al. 2010; Delextrat & Cohen, 2008). For the most part, these tests are not indicative of the overall demands experienced by basketball players during competition, as they do not account for the unique intermittent requirements, basketball-specific movements, and activity intensities likely to occur during matches. As such, with the acquisition of current basketball TMA data, a simulation test that reliably and validly reflects basketball match activity demands may be developed. It has previously been
suggested that simulation tests may allow for the most effective assessments of match-related fitness within team sport athletes (Müller, Benko, Raschner & Schwameder, 2000). Thus the development of a basketball simulation test may add further benefit to various coaching, conditioning, and research practices within the sport.

1.1 STATEMENT OF THE RESEARCH PROBLEM

To date, no research has described the match activity demands of current open-age male basketball players within Australia or globally. Furthermore, there is a limited understanding of differences in match demands across basketball competition levels. Thus, without such data, precise assessments of basketball-related fitness using match-specific test protocols are presently not possible. Thus, in order to facilitate the development of a basketball simulation test specific to the match activity demands of open-age male competition, more research is required.

1.2 PURPOSE OF THE THESIS

Therefore, the present thesis has a number of purposes:

- To describe the current activity demands of open-age Australian male basketball competition.
- To compare the match activity demands of current elite and sub-elite Australian male basketball competitions.
- To examine the intra-match variation in activity requirements during elite and sub-elite Australian male basketball competitions.
- To develop a basketball simulation test specific to the activity demands of current open-age Australian male basketball competition.
- To determine the reliability and validity of the developed basketball simulation test.
1.3 SIGNIFICANCE OF THE THESIS

There is a limited understanding of the precise activity demands of current open-age male basketball competition internationally and even more so within Australia. Further, no basketball-specific fitness tests have been developed that simulate the activity requirements of open-age male competition. The present thesis aims to provide the first description of the current match activity demands imposed upon elite and sub-elite open-age Australian male basketball players. Using these data, this thesis aims to present the first reliable and valid basketball simulation test specific to the current activity demands of open-age Australian male match play.

1.4 LIMITATIONS OF THE THESIS

The following limitations may apply to the present series of studies:

- **Specificity of the results**
  The data collected during the present thesis are representative of the elite, sub-elite, and regional basketball players included within this research. Therefore the results may not be applicable to other basketball players of different ages, gender, geographical locations, and playing levels.

- **Competition factors**
  A characteristic of most team sports is that various competition factors can influence the demands imposed upon players within and across matches. These factors may include coaching tactics, playing venue, opposition ability, match score and importance, and refereeing decisions. While the analysis of multiple matches is likely to minimise the impact of these factors on the resultant activity data, they should be acknowledged when interpreting the present findings.

- **Movement categorisation**
  Within the present TMA methodology, movement categorisation was not developed to identify multi-directional activity, player-specific movement velocities, or team role, such as offensive and defensive phases.
• **Acceleration data**

The present TMA methodology did not allow the calculation of player accelerations and decelerations. Such analysis would provide more in-depth data concerning the physical loads placed upon players during competitive matches.

• **Physiological data**

The collection of physiological data during match play was not included within the present thesis due to competition constraints. The acquisition of such information may have complemented the provided TMA data and provided greater insight into basketball match demands.

### 1.5 DELIMITATIONS OF THE THESIS

The following delimitations may apply to the present series of studies:

• **Sport restriction of participants**

The participants recruited within the present thesis were restricted to basketball players. Therefore, the present results may not be applicable to other team sport athletes.

• **Competition restriction of participants**

The participants recruited within the present research were restricted to basketball players competing within the National Basketball League (NBL), Queensland Basketball League (QBL), and regional basketball competitions. Therefore, the present results may not be applicable to basketball players from other competitions.
1.6 ASSUMPTIONS OF THE THESIS

The following assumptions may apply to the present series of studies:

• *Condition of players*
  
  Given that the acquisition of activity data was performed across competitive seasons lasting a number of months, it is assumed that the investigated players maintained their training habits throughout all matches included within the present analysis.

• *Participant compliance*
  
  All participants undergoing performance testing were advised to and thus assumed to have followed the set standardised dietary and exercise guidelines prior to the commencement of each testing session.
Chapter 2

Review of Literature
2.0 INTRODUCTION

Whilst basketball remains a popular sport worldwide, little is known about the activity demands experienced by open-age male players during competition. To date, most of the existing research examining the competition demands of basketball has described the physiological responses of players across matches (Beam & Merrill, 1994; Ben Abdelkrim et al. 2010a, 2009, 2007; Janeira & Maia, 1998; Matthew & Delextrat, 2009; McArdle et al. 1971; McInnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Rodriguez-Alonso et al. 2003; Tessitore et al. 2006; Vaquera Jimenez et al. 2008), with fewer studies reporting on player activity responses (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Erculj et al. 2008; Janeira & Maia, 1998; Matthew & Delextrat, 2009; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006).

The activity demands of basketball competition refer to the movement types and velocities performed during match play. Within the existing research, the activity demands of basketball competition have been examined across age-restricted (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006) and practice matches (Narazaki et al. 2009; Tessitore et al. 2006), within female athletes (Matthew & Delextrat, 2009; Narazaki et al. 2009), or using non-specific movement categories (Bishop & Wright, 2006; Erculj et al. 2008; Narazaki et al. 2009; Tessitore et al. 2006). Furthermore, only one study has described the activity demands of Australian male basketball competition, and these data were measured during pre-season matches following superseded rules (McInnes et al. 1995). In addition, only one study to date has compared match activity demands between competition levels, and these observations were made within junior players (Ben Abdelkrim et al. 2010a). Therefore, no research has described the precise activity demands of current Australian or open-age male basketball competition or compared these demands between playing levels.

The provision of competition activity data is essential in the development of team sport simulation tests. Such tests enable the physical requirements of team sport competition to be replicated within controlled environments, and the match-related fitness of athletes to be precisely assessed (Müller et al. 2000). However, no simulation tests have been
developed that are specific to complete basketball match activity. This can largely be attributed to the paucity of available data detailing the activity requirements of open-age male basketball competition. Thus, more research is needed describing the activity demands of open-age male basketball competition for the development of a match-specific basketball simulation test.

To provide a theoretical framework for the present thesis, this review will address a number of key issues within the context of existing research. Firstly, the present review will describe basketball competition factors that may influence the match demands imposed upon players. Secondly, the anthropometric and fitness characteristics of male basketball players are explored to provide an indication of the physical attributes and performance capacities likely to be important within the sport. Thirdly, existing research examining the physiological and activity responses of male players during competition is discussed to provide an understanding of basketball match demands. Fourthly, differences in player fitness, performance characteristics, and match responses between basketball competition levels are identified to establish the likely influence of playing standard on match demands. Finally, methodological aspects involved in the development of team sport and basketball simulation tests are discussed to better understand the procedures involved in this process and the current status of fitness tests within basketball. As such, this review includes six primary areas relevant to the present thesis:

- Basketball competition factors;
- Anthropometric and physiological fitness characteristics of male basketball players;
- Physiological demands of male basketball competition;
- Activity demands of male basketball competition;
- Differences between basketball competition levels in male basketball;
- The development of team sport simulation tests.
2.1 BASKETBALL COMPETITION FACTORS

The match activity demands of athletes have been extensively described within many team sports, including soccer (Andersson, Randers, Heiner-Møller, Krstrup & Mohr, 2010; Bangsbo, Mohr & Krstrup, 2006; Burgess, Naughton & Norton, 2006; Mohr, Krstrup, Andersson, Kirkendal & Bangsbo, 2008), rugby league (Sirotic et al. 2009), rugby union (Deutsch, Kearney & Rehrer, 2007), futsal (Barbero-Alvarez, Soto, Barbero-Alvarez & Granda-Vera, 2008), Australian Rules football (Brewer et al. 2010; Coutts, Quinn, Hocking, Castagna & Rampinini, 2010b; Dawson, Hopkinson, Appleby, Stewart & Roberts, 2004), field hockey (Spencer et al. 2004), and water polo (Platanou & Geladas, 2006). However, most existing research describing the demands of basketball competition has reported on the physiological responses of players during matches. The primary physiological responses investigated to date include heart rate (HR) and blood lactate concentration ([BLa]). Therefore, most researchers have made assumptions based on indirect physiological measures to describe the match demands placed on basketball players. Furthermore, while increased research attention has been given to the activity requirements of basketball competition in recent years, existing data do not reflect the current match demands for open-age Australian male players. This in part can be attributed to previous rule changes and variations in match format between geographical regions.

Within existing literature examining the match demands of basketball competition, two major factors must be addressed. Firstly, the sport of basketball underwent global rule changes in 2000, which is likely to have altered the competition demands placed upon players. Secondly, the geographical differences in numerous competition factors such as style of play, rules and regulations, and competition scheduling and type, are likely to influence the demands imposed upon players during basketball match play. As such, these factors should be considered when interpreting and making comparisons to existing basketball research.
2.1.1 Basketball Rule Changes

Over the past decade, basketball underwent major rule changes initiated by the governing body International Basketball Federation (FIBA). Three of these rule amendments have impacted on the match format and possibly the physical demands imposed upon players during competition (Cormery et al. 2008). Firstly, the attack time (shot clock duration) for the offensive team was reduced from 30 s to 24 s. Secondly, the time permitted for the offensive team to move the ball across the half-way line from the backcourt was reduced from 10 s to 8 s. Finally, the match format was altered to include quarters, rather than halves.

These rule changes have been suggested to increase the physiological and activity requirements placed on basketball players throughout matches (Cormery et al. 2008). Recently, Cormery et al. (2008) reported no significant changes in the anthropometric characteristics (age, stature, body mass, and body composition) of elite French male basketball players across a 10-yr period (1994-2004). However, there was a reported significant increase in sub-maximal (42.6 ± 1.4 vs. 52.1 ± 1.3 ml·kg⁻¹·min⁻¹) and maximal oxygen consumption (V̇O₂max) (51.0 ± 1.6 vs. 63.4 ± 2.7 ml·kg⁻¹·min⁻¹) in guards (G) across this same period. Small (effect size (ES) = 0.2) changes in V̇O₂max were observed in forwards (F) across this period (45.2 ± 1.6 vs. 45.5 ± 0.8 ml·kg⁻¹·min⁻¹), whilst a very large (ES = 2.9) increase was observed in centres (C) (40.4 ± 1.3 vs. 44.8 ± 1.7 ml·kg⁻¹·min⁻¹). It was proposed that the changes in match format elicited an increase in sprint frequency, reduced recovery time between sprints, and an increase in the distance covered by players during competition (Cormery et al. 2008). As such, both the anaerobic and aerobic demands of the sport have been suggested to have increased as a result of the aforementioned rule changes (Cormery et al. 2008).

Although the research conducted by Cormery et al. (2008) is novel in its approach, an inherent problem is evident. The research was carried out over a 10-yr period, which resulted in high player turnover across the study. This created constant changes in the tested athletes and therefore factors such as player conditioning, skill level, professionalism
within the sport, and genetic attributes could not be controlled. Despite the faults that come with such retrospective studies, the information provided is certainly valuable. Furthermore, recent research investigating the physiological and activity demands imposed upon basketball players during competition partly attributed variations in the observed responses compared with previous findings to the changes in match format (Ben Abdelkrim et al. 2007). Ben Abdelkrim et al. (2007) proposed that a shortening of the offensive attack time from 30 s to 24 s limited the amount of long tactical plays that were able to be executed and increased the frequency of transitions up and down the court. It was suggested that this would raise the activity intensity and physical demands of basketball competition (Ben Abdelkrim et al. 2007).

While it is difficult to make definitive conclusions concerning the effects of the rule changes on basketball competition demands, they are likely to influence player workloads across matches. However, more research directly assessing the effects of the rule amendments on basketball competition demands using the same participant sample is needed to validate this suggestion.

2.1.2 Differences between Geographical Regions

In addition to the basketball rule changes, other less obvious factors may also affect the resulting match demands placed upon players. The geographic location of the competition seems to be a predominant factor in explaining variations evident between reported basketball demands. Earlier research examined the physiological and activity workloads imposed upon elite Australian open-age male basketball players (McInnes et al. 1995), whereas more recent research has investigated the responses of European (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Erculj et al. 2008; Tessitore et al. 2006) and American male players (Narazaki et al. 2009). Moreover, previous researchers have also reported geographical variations in the anthropometric and fitness characteristics of male basketball players (Ben Abdelkrim et al. 2010a, 2007; Drinkwater, Hopkins, McKenna, Hunt Pyne, 2007; Latin, Berk & Baechle, 1994). As such, many aspects of basketball performance,
including the conditioning of players, styles of play, and external factors may explain some of the discrepancies evident between Australian, European, and American competitions.

### 2.1.2.1 Player Conditioning

It has previously been suggested that player conditioning has an effect on the activity of basketball players during competition (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Previously, a greater $\dot{V}O_{2\text{max}}$ has been observed within elite Australian male players (60.7-68.6 ml·kg$^{-1}$·min$^{-1}$) (McInnes et al. 1995; Montgomery et al. 2010) compared with elite European male players (44.1-54.4 ml·kg$^{-1}$·min$^{-1}$) (Apostolidis, Nassis, Bolatoglou & Geladas, 2003; Ben Abdelkrim et al. 2010a, 2010b, 2007; Gocentus, Juozulynas, Obelenis, Andziulis & Landor, 2005; Laplaud, Hug & Menier, 2004; Metaxas, Koutlianos, Sendelides & Mandroukas, 2009; Ostojic, Mazic & Dikic, 2006). It has been suggested that differences in aerobic capacity between Australian and European players may be a contributing factor to the varied match activity demands observed within these regions (Ben Abdelkrim et al. 2007). However, recent research has reported considerably higher $\dot{V}O_{2\text{max}}$ in European male players than earlier research indicates. Castagna et al. (2009, 2007), Sallet et al. (2005), and Cormery et al. (2008) reported $\dot{V}O_{2\text{max}}$ values between 57.5-63.4 ml·kg$^{-1}$·min$^{-1}$ in Italian regional and national French male players, suggesting that aerobic conditioning may vary between European competitions. Furthermore, other studies investigating the anthropometric and fitness characteristics of basketball players have reported $\dot{V}O_{2\text{max}}$ measures within both North (Caterisano, Patrick, Edenfield & Batson, 1997; Latin et al. 1994; Narazaki et al. 2009; Parr, Wilmore, Hoover, Bachman & Kerlan, 1978) and South American players (Tavino et al. 1995).

Early research reported $\dot{V}O_{2\text{max}}$ values of 41.9-50.0 ml·kg$^{-1}$·min$^{-1}$ in elite male players from the United States (US) (Parr et al. 1978). More recently however, higher $\dot{V}O_{2\text{max}}$ (55.0-57.5 ml·kg$^{-1}$·min$^{-1}$) have been observed within various US male basketball competitions (Caterisano et al. 1997; Latin et al. 1994; Narazaki et al. 2009), suggesting that the aerobic conditioning of American players has improved or competition demands have increased in recent years. Furthermore, Tavino et al. (1995) reported that the $\dot{V}O_{2\text{max}}$ of Brazilian male
basketball players of 65.2 ± 6.2 ml·kg⁻¹·min⁻¹ is comparable to that reported for Australian players (McInnes et al. 1995). This body of research suggests that Australian and American players possess greater aerobic fitness than the majority of their European counterparts. These findings may be indicative of disparities in match demands between geographical regions, considering VO₂max has been observed to be significantly related to distance covered performing high-intensity activity (HIA) and maximal-speed running during basketball competition (Ben Abdelkrim et al. 2010b). However, differences in the methodologies used to assess VO₂max and the competition levels of the investigated players between studies cannot be discounted as contributory factors.

In addition to aerobic fitness, other power-based measures have been assessed within basketball players from different geographical locations. European male players have been observed to possess lower power outputs (PO) as measured through vertical jump height (VJH) than Australian and American male players (Apostolidis et al. 2003; Ben Abdelkrim et al. 2010c; Castagna et al. 2009; Drinkwater et al. 2007; Greene et al. 1998; Khlifa et al. 2010; Latin et al. 1994; Montgomery et al. 2008a; Ostojic et al. 2006). Montgomery et al. (2008a) and Drinkwater et al. (2007) reported state-level Australian male basketball players to possess a VJH of between 59.1-62.0 cm. Further, research examining the VJH of high-school and collegiate American male basketball players reported measures of 64.0-73.4 cm (Greene et al. 1998; Latin et al. 1994). These values are mostly greater than those previously observed in elite Tunisian (49.0-61.9 cm) (Ben Abdelkrim et al. 2010c; Chaouachi et al. 2009; Khlifa et al. 2010), Serbian (54.6-59.7 cm) (Ostojic et al. 2006), Italian (47.0-48.1 cm) (Castagna et al. 2009), and Greek male players (39.8 ± 3.7 cm) (Apostolidis et al. 2003). These findings suggest that Australian and American basketball programs may incorporate more extensive power training than European teams. Alternatively, given that jumping ability has been reported to be significantly related to playing time during basketball competition (Hoffman, Tenenbaum, Maresh & Kraemer, 1996a), the explosive activity demands of matches within Australian and American regions may be greater than in European competitions.
While data describing the fitness characteristics of players provide insight concerning differences in conditioning between geographical regions, it is difficult to gather a definitive conclusion considering the variations within existing methodologies, testing devices, and results. Furthermore, discrepancies between regions may in part be specific to each team, and not necessarily an indication of all players within that region. However, identified trends in other factors between regions, such as playing style, suggest that competition location may have a direct impact on basketball match demands.

2.1.2.2 Playing Style

Observed variations in the match demands imposed upon male basketball players within the available literature may in part be due to differences in the playing style between regions. Recently, it has been suggested that changes in the proportion of and structure of defensive and offensive play are likely to elicit varied demands on elite male basketball players across matches (Ben Abdelkrim et al. 2010a; Montgomery et al. 2010). Ben Abdelkrim et al. (2010a) recently examined the physical demands of different defensive strategies and observed man-to-man defensive structures (67 ± 13) to elicit significantly more sprinting bouts than zone (37 ± 19) defences. Additionally, when comparing the demands of defensive and offensive activity, Montgomery et al. (2010) reported that defensive play (HR: 152 ± 7 b·min⁻¹; oxygen consumption (VO₂): 45.1 ± 3.6 ml·kg⁻¹·min⁻¹) imposed a greater physiological load than offensive play (HR: 147 ± 5 b·min⁻¹; VO₂: 42.3 ± 3.0 ml·kg⁻¹·min⁻¹) in elite junior Australian male basketball players. Taken together, these findings highlight the different physiological requirements of specific basketball tactical strategies and playing phases. Consequently, teams adopting a defensive approach to matches may experience greater competition demands than offensive-minded teams.

It might be suggested that different geographical competitions may adopt specific styles of play suited to the anthropometric and fitness characteristics of players within that area. As such, given the reported differences in these characteristics between regions, playing styles may also differ. However, tactical play is likely to vary within teams and competitions, and depend greatly on the opposition faced. It is also probable that style of play will be affected
by external factors, such as match rules, and competition scheduling and type within
different geographical regions.

2.1.2.3 External Factors

Although the same set of rules and regulations govern basketball competition across the
world, some minor match format variations do exist and suggest differences in competition
demands may exist geographically. These variations largely involve the time restrictions and
game durations experienced during competition. For example, the professional American
competition (National Basketball Association (NBA)) involves matches lasting 48 min (Deitch,
Starkey, Walters & Moseley, 2006), as opposed to the 40-min durations employed within
international-based (FIBA, 2006), female (Deitch et al. 2006), collegiate (Harari & Ominsky,
2006), and most European competitions (Cormery et al. 2008). Previously, elite Australian
basketball matches have been played across 48 min. However, recently (2010) the matches
have been reduced to 40 min. Similarly, variations in shot clock duration are also evident
between some competitions, namely professional (24 s) and collegiate (35 s) leagues (Harari
& Ominsky, 2006). Differences in the time constraints and game durations experienced by
basketball players are likely to directly affect the type and quantity of activity performed, as
well as tactical decisions made during matches. Subsequently, these differences should be
taken into account when interpreting the reported match demands of basketball
competition.

Another external factor potentially influencing player conditioning, fatigue, and playing style,
is competition scheduling. It has been suggested that professional European players must
compete in multiple national and European competitions, and participate in two games
every five days on average (Cormery et al. 2008). Similar demands are placed on
professional American male basketball players, with competition comprising 82 games over
a 30-week period during the regular season (Deitch et al. 2006). However, in other countries,
such as Australia, players compete much less frequently across a shorter playing season,
generally participating in 1-2 games per week (McInnes et al. 1995). The frequency of
competitive matches and playing season length are likely to influence player performance
and fatigue during matches through limiting available recovery opportunity. Consequently, these factors may affect the match activity profiles of players across the course of a season. When reviewing the existing body of research examining basketball competition demands, the type of competition being investigated must also be considered. Players may compete within practice matches, pre-season tournaments, regular season matches, or playoff series. The type of competition should be noted when interpreting the match demands of basketball competition and the highest level of competition should be included within the methodologies of such research. This is due to variations in player effort and fitness that can accompany different seasonal periods and competition types. Factors such as player motivation, training status, and psychological importance may all vary with different competition types, possibly influencing activity responses across matches. Recent research reporting lower HR, [BlA\textsuperscript{−}], and VO\textsubscript{2} demands in basketball players during practice activity compared to actual competition supports this suggestion (Montgomery et al. 2010; Rodriguez-Alonso et al. 2003).

Although the discussed rule changes and regional differences in basketball competition have not been extensively addressed within existing literature, they should be acknowledged when interpreting research describing player characteristics and match demands. The following sections of this review will summarise the existing literature detailing the anthropometric and fitness characteristics of male basketball players, as well as the physiological and activity demands of male basketball competition.

2.2 ANTHROPOMETRIC AND FITNESS CHARACTERISTICS OF MALE BASKETBALL PLAYERS

The majority of existing research examining male basketball competition has reported on both the anthropometric and fitness characteristics of players (Apostolidis et al. 2003; Balciunas, Stonkus, Abrantes & Sampaio, 2006; Ben Abdelkrim et al. 2010a, 2010b, 2007; Carvalho et al. 2011; Castagna et al. 2009, 2007; Caterisano et al. 1997; Cook, Kiss, Khan, Purdam & Webster, 2004; Cormery et al. 2008; Delextrat & Cohen, 2008; Drinkwater et al. 2007; Kalinski, Norkowski, Kerner & Tkaczuk, 2002; Khlifa et al. 2010; Latin et al. 1994;
McInnes et al. 1995; Metaxas et al. 2009; Montgomery et al. 2008a, 2010; Parr et al. 1978; Sallet et al. 2005; Tavino et al. 1995). It has previously been suggested that player attributes such as body composition, PO, and anaerobic and aerobic capacity are of the utmost importance in basketball (Ostojic et al. 2006). The measurement of anthropometric and fitness characteristics within basketball players also provides an indication of player conditioning, which may allow inferences to be made concerning basketball match demands.

2.2.1 Anthropometric Data

The anthropometric profiles of basketball players from various playing standards have been readily determined within existing literature. Basketball players typically possess a wide range of anthropometric characteristics due to differences in positional requirements and competition levels (Trninic & Dizdar, 2000). Within existing research, the major anthropometric measures investigated include body mass, stature, and body composition. A summary of existing research describing the anthropometric characteristics of male basketball players is presented in Table 2.1.

2.2.1.1 Body Mass

To date, many studies have reported the body mass of male basketball players, and within this literature some major trends are evident. Early research examining elite American male basketball players reported forwards (96.9 ± 7.3 kg) to be heavier than guards (83.6 ± 6.3 kg), and centres (109.2 ± 13.8 kg) to be heavier than both positions (Parr et al. 1978). More recent research observed similar trends in the positional body mass of first division collegiate American male basketball players (G: 82.9 ± 6.8 kg; F: 95.1 ± 8.3 kg; C: 101.9 ± 9.7 kg) (Latin et al. 1994). Comparable body mass measurements have also been observed in elite Australian players (G: 79.4 ± 8.7 kg; F/C: 97.6 ± 7.6 kg), as well as young adult and open-age (18.3-27.0 ± 0.5-5.5 yr) European male players.
Table 2.1: A summary of existing research describing the anthropometric measurements of male basketball players.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Positions</th>
<th>Age (yr)</th>
<th>Body Mass (kg)</th>
<th>Stature (cm)</th>
<th>Body Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apostolidis et al. (2003)</td>
<td>Int Junior Greece</td>
<td>Guards (n = 6)</td>
<td>18.3 ± 0.5</td>
<td>88.0 ± 4.8</td>
<td>194 ± 4</td>
<td>9.1 ± 1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forwards (n = 4)</td>
<td>18.5 ± 0.6</td>
<td>99.8 ± 4.8</td>
<td>203 ± 4</td>
<td>11.8 ± 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centres (n = 3)</td>
<td>18.7 ± 0.6</td>
<td>104.9 ± 5.1</td>
<td>206 ± 2</td>
<td>13.8 ± 2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All (n = 13)</td>
<td>18.5 ± 0.5</td>
<td>95.5 ± 8.8</td>
<td>200 ± 6</td>
<td>11.0 ± 2.5</td>
</tr>
<tr>
<td>Balciunas et al. (2006)</td>
<td>Int Junior Lithuanian</td>
<td>All (n = 35)</td>
<td>15-16</td>
<td>73.2-77.1 ± 5.1</td>
<td>181-185 ± 5-8</td>
<td>N/A</td>
</tr>
<tr>
<td>Barfield et al. (2007)</td>
<td>Collegiate US</td>
<td>All (n = 18)</td>
<td>20.3 ± 1.7</td>
<td>83.1 ± 10.7</td>
<td>187 ± 9</td>
<td>18.3 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>High-School US</td>
<td>All (n = 17)</td>
<td>16.3 ± 1.0</td>
<td>73.9 ± 13.3</td>
<td>182 ± 9</td>
<td>18.5 ± 0.6</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2010a)</td>
<td>Int/Nat Junior Tunisian</td>
<td>Int (n = 17)</td>
<td>18.3 ± 0.4</td>
<td>81.2 ± 7.4</td>
<td>188 ± 6</td>
<td>6.4 ± 4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nat (n = 22)</td>
<td>18.2 ± 0.5</td>
<td>79.6 ± 6.3</td>
<td>189 ± 4</td>
<td>9.6 ± 5.9</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2010c)</td>
<td>Int Tunisian</td>
<td>Under 18 yr (n = 15)</td>
<td>17.5 ± 3.0</td>
<td>83.7 ± 8.2</td>
<td>192 ± 7</td>
<td>12.6 ± 3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Under 20 yr (n = 15)</td>
<td>19.5 ± 4.0</td>
<td>91.4 ± 8.3</td>
<td>199 ± 7</td>
<td>10.2 ± 2.4</td>
</tr>
<tr>
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<td></td>
<td>Senior (n = 15)</td>
<td>25.4 ± 3.0</td>
<td>91.5 ± 7.2</td>
<td>198 ± 6</td>
<td>9.8 ± 2.5</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2007)</td>
<td>Nat Junior Tunisian</td>
<td>Guards (n = 8)</td>
<td>18.2 ± 0.2</td>
<td>76.2 ± 3.4</td>
<td>183 ± 4</td>
<td>6.1 ± 3.7</td>
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<td>Forwards (n = 18)</td>
<td>18.2 ± 0.5</td>
<td>77.4 ± 5.1</td>
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<td>7.8 ± 4.1</td>
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<td>Centres (n = 12)</td>
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<td>87.2 ± 5.3</td>
<td>193 ± 3</td>
<td>10.4 ± 7.8</td>
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<td></td>
<td>All (n = 38)</td>
<td>18.2 ± 0.5</td>
<td>80.3 ± 6.7</td>
<td>189 ± 5</td>
<td>8.2 ± 5.6</td>
</tr>
<tr>
<td>Carvalho et al. (2011)</td>
<td>Nat/Local Junior Portuguese</td>
<td>All (n = 76)</td>
<td>15.2 ± 0.5</td>
<td>68.2 ± 9.5</td>
<td>178 ± 10</td>
<td>N/A</td>
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<tr>
<td>Castagna et al. (2009)</td>
<td>Regional Italian</td>
<td>Junior (n = 11)</td>
<td>16.7 ± 1.2</td>
<td>69.3 ± 5.9</td>
<td>181 ± 6</td>
<td>10.0 ± 0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Senior (n = 11)</td>
<td>24.5 ± 3.5</td>
<td>84.4 ± 11.4</td>
<td>192 ± 9</td>
<td>10.0 ± 1.2</td>
</tr>
<tr>
<td>Castagna et al. (2007)</td>
<td>Competitive Junior Italian</td>
<td>All (n = 18)</td>
<td>16.8 ± 1.2</td>
<td>73 ± 10</td>
<td>181 ± 6</td>
<td>N/A</td>
</tr>
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<td>Castagna et al. (2010)</td>
<td>Regional Junior Italian</td>
<td>All (n = 14)</td>
<td>15.3 ± 0.6</td>
<td>72 ± 6.3</td>
<td>182 ± 5</td>
<td>N/A</td>
</tr>
<tr>
<td>Caterisano et al. (1997)</td>
<td>Collegiate US</td>
<td>All (n = 9)</td>
<td>21.0 ± 0.7</td>
<td>92.2 ± 8.2</td>
<td>N/A</td>
<td>5.9 ± 3.1</td>
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<tr>
<td>Chaouachi et al. (2009)</td>
<td>Int Tunisian</td>
<td>All (n = 14)</td>
<td>23.3 ± 2.7</td>
<td>94.2 ± 10.2</td>
<td>196 ± 8</td>
<td>14.0 ± 3.7</td>
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<td>Cook et al. (2004)</td>
<td>High Performance Junior Australian</td>
<td>All (n = 38)</td>
<td>14-18</td>
<td>81.4 ± 9.5</td>
<td>191 ± 9</td>
<td>N/A</td>
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<tr>
<td>Cormery et al. (2008)</td>
<td>Nat French</td>
<td>Guards (n = 10)</td>
<td>27 ± 2.1</td>
<td>79.5 ± 2.9</td>
<td>184 ± 2</td>
<td>13.5 ± 0.9</td>
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<td></td>
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<td>Forwards (n = 19)</td>
<td>25 ± 1.4</td>
<td>96.3 ± 2.0</td>
<td>200 ± 1</td>
<td>13.6 ± 0.6</td>
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<tr>
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<td></td>
<td>Centres (n = 8)</td>
<td>21 ± 3.2</td>
<td>110.0 ± 4.4</td>
<td>208 ± 3</td>
<td>14.9 ± 1.3</td>
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<tr>
<td>Delextrat &amp; Cohen (2008)</td>
<td>University First/Second Teams</td>
<td>First (n = 8)</td>
<td>25.4 ± 2.4</td>
<td>90.6 ± 8.1</td>
<td>192 ± 9</td>
<td>12.0 ± 5.0</td>
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<td></td>
<td>Second (n = 8)</td>
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<td>187 ± 6</td>
<td>12.5 ± 4.7</td>
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<td>Drinkwater et al. (2007)</td>
<td>Nat/State Australian</td>
<td>Nat (n = 129)</td>
<td>17.1 ± 1.0</td>
<td>84 ± 10.3</td>
<td>195 ± 9</td>
<td>N/A</td>
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<td></td>
<td>State (n = 958)</td>
<td>15.7 ± 0.9</td>
<td>77.3 ± 11.0</td>
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<td>N/A</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Group</td>
<td>Sample Size</td>
<td>Age (mean ± SD)</td>
<td>Height (mean ± SD)</td>
<td>Weight (mean ± SD)</td>
</tr>
<tr>
<td>-------------------------------</td>
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<tr>
<td>Gocentas et al. (2007)</td>
<td>Int European</td>
<td>All (n = 33)</td>
<td>24.7 ± 3.8</td>
<td>96.2 ± 12.3</td>
<td>198 ± 10</td>
<td>N/A</td>
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<td>Greene et al. (1998)</td>
<td>High-School US</td>
<td>All (n = 61)</td>
<td>16.2 ± 1.1</td>
<td>75.0 ± 12.0</td>
<td>182 ± 8</td>
<td>12.0 ± 4.3</td>
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<tr>
<td>Hoffman et al. (1999)</td>
<td>Nat Israeli</td>
<td>All (n = 20)</td>
<td>19.0 ± 1.7</td>
<td>88.4 ± 8.0</td>
<td>194 ± 6</td>
<td>12.9 ± 3.1</td>
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<tr>
<td>Kalinksi et al. (2002)</td>
<td>Nat Polish</td>
<td>All (n = 54)</td>
<td>24.2 ± 3.3</td>
<td>91.0 ± 10.5</td>
<td>197 ± 8</td>
<td>N/A</td>
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<tr>
<td>Laplaud et al. (2004)</td>
<td>Nat French</td>
<td>All (n = 8)</td>
<td>N/A</td>
<td>95 ± 10</td>
<td>198 ± 8</td>
<td>N/A</td>
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<tr>
<td>Latin et al. (1994)</td>
<td>Collegiate US</td>
<td>Guards</td>
<td>N/A</td>
<td>82.9 ± 6.8 (n = 185)</td>
<td>187 ± 6 (n = 185)</td>
<td>8.4 ± 3.0 (n = 113)</td>
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<td></td>
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<td>Forwards</td>
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<td>95.1 ± 8.3 (n = 153)</td>
<td>198 ± 4 (n = 152)</td>
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<td>Centres</td>
<td></td>
<td>101.9 ± 9.7 (n = 90)</td>
<td>206 ± 6 (n = 90)</td>
<td>11.2 ± 4.5 (n = 53)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All</td>
<td></td>
<td>91.3 ± 11.1 (n = 428)</td>
<td>195 ± 9 (n = 427)</td>
<td>9.4 ± 3.8 (n = 255)</td>
</tr>
<tr>
<td>McInnes et al. (1995)</td>
<td>Nat Australian</td>
<td>Guards (n = 3)</td>
<td>24.0 ± 2.6</td>
<td>79.4 ± 7.7</td>
<td>181 ± 10</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forwards/Centres (n = 5)</td>
<td>23.2 ± 3.7</td>
<td>97.6 ± 7.6</td>
<td>197 ± 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>All (n = 8)</td>
<td>23.5 ± 3.2</td>
<td>90.8 ± 11.8</td>
<td>191 ± 10</td>
<td></td>
</tr>
<tr>
<td>Metaxas et al. (2009)</td>
<td>Nat Greek</td>
<td>Division I (n = 14)</td>
<td>23.6 ± 3.1</td>
<td>95.8 ± 11.5</td>
<td>193 ± 8</td>
<td>11.0 ± 1.6</td>
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<td>Division II (n = 15)</td>
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<td>92.0 ± 15.1</td>
<td>191 ± 10</td>
<td>11.9 ± 2.3</td>
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<td>Division III (n = 17)</td>
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<td>91.4 ± 12.8</td>
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<td>Division IV (n = 15)</td>
<td>20.8 ± 3.4</td>
<td>94.6 ± 11.5</td>
<td>190 ± 6</td>
<td>14.3 ± 3.4</td>
</tr>
<tr>
<td>Montgomery et al. (2008a)</td>
<td>Elite Junior Australian</td>
<td>All (n = 29)</td>
<td>19.1 ± 2.1</td>
<td>88.5 ± 14.7</td>
<td>184 ± 3</td>
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</tr>
<tr>
<td>Montgomery et al. (2010)</td>
<td>Elite Junior Australian</td>
<td>All (n = 11)</td>
<td>19.1 ± 2.1</td>
<td>87.9 ± 15.1</td>
<td>191 ± 9</td>
<td>N/A</td>
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<tr>
<td>Narazaki et al. (2009)</td>
<td>Collegiate US</td>
<td>All (n = 6)</td>
<td>20.8 ± 1.0</td>
<td>91.9 ± 17.5</td>
<td>192 ± 12</td>
<td>9.7 ± 5.9</td>
</tr>
<tr>
<td>Ostojic et al. (2006)</td>
<td>Nat Serbian</td>
<td>Guards (n = 20)</td>
<td>25.6 ± 3.2</td>
<td>88.6 ± 8.1</td>
<td>191 ± 6</td>
<td>9.9 ± 3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forwards (n = 20)</td>
<td>21.4 ± 2.8</td>
<td>95.7 ± 7.1</td>
<td>200 ± 3</td>
<td>10.1 ± 3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centres (n = 20)</td>
<td>23.2 ± 3.2</td>
<td>105.1 ± 11.5</td>
<td>208 ± 3</td>
<td>14.4 ± 5.6</td>
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<tr>
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<td>All (n = 60)</td>
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<td>96.5 ± 11.2</td>
<td>200 ± 8</td>
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</tr>
<tr>
<td>Parr et al. (1978)</td>
<td>Nat US</td>
<td>Guards</td>
<td>N/A</td>
<td>83.6 ± 6.3</td>
<td>188 ± 10</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forwards</td>
<td></td>
<td>96.9 ± 7.3</td>
<td>201 ± 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centres</td>
<td></td>
<td>109.2 ± 13.8</td>
<td>214 ± 5</td>
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<td>Sallet et al. (2005)</td>
<td>First/Second Division French</td>
<td>Guards (n = 14)</td>
<td>23.6 ± 4.3</td>
<td>82.0 ± 8.8</td>
<td>186 ± 7</td>
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<td></td>
<td>Forwards (n = 22)</td>
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<td>89.4 ± 7.1</td>
<td>196 ± 5</td>
<td>11.4 ± 2.3</td>
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<td>Centres (n = 22)</td>
<td>24.5 ± 4.7</td>
<td>103.9 ± 12.4</td>
<td>204 ± 5</td>
<td>14.4 ± 3.7</td>
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<td>All (n = 58)</td>
<td>24.1 ± 5.8</td>
<td>93.1 ± 13.2</td>
<td>196 ± 9</td>
<td>12.6 ± 3.1</td>
</tr>
<tr>
<td>Tavino et al. (1995)</td>
<td>Nat Brazilian</td>
<td>All (n = 9)</td>
<td>N/A</td>
<td>87.7 ± 6.7</td>
<td>N/A</td>
<td>9.8 ± 1.9</td>
</tr>
<tr>
<td>Vaquera Jimenez et al. (2008)</td>
<td>Nat Spanish</td>
<td>All (n = 8)</td>
<td>27.5 ± 11.6</td>
<td>91.3 ± 19.3</td>
<td>195 ± 15</td>
<td>9.7 ± 6.4</td>
</tr>
</tbody>
</table>

US = United States; Int = International; Nat = National; All = All players; N/A = Data not available.
Previously, Apostolidis et al. (2003), Cormery et al. (2008), Sallet et al. (2005), and Ostojic et al. (2006) reported comparable positional body masses (G: 79.5-88.6 kg; F: 89.4-99.8 kg; C: 103.9-110.0 kg) in elite Greek, French, and Serbian male players to those observed in Australian and American players. As expected, lower body masses have been reported for elite junior (15.0-17.5 yr) European male players (68.2-83.7 kg) (Balciunas et al. 2006; Ben Abdelkrim et al. 2010c; Carvalho et al. 2011; Castagna et al. 2009, 2010). These findings suggest that there are few differences in positional body mass measurements and trends between regions. The greater differences in body mass between player age-groups are to be expected due to the previously reported changes in body size that accompany maturation within junior athletes (Coelho E Silva, Figueiredo, Moreira Carvalho & Malina, 2008).

The positional trends evident in the body mass of male basketball players can in large be attributed to the demands placed on each position during competition. Centres and forwards require a greater body mass for gaining physical position closer to the basket to complete various tasks including rebounding, shot-blocking, and applying defensive pressure. Furthermore, due to these positional requirements, body mass may be a determinant during the selection process for coaches, with heavier players being selected for forward/centre positions. However, this may in turn be related to the relationship evident between body mass and stature within male basketball players, and the importance placed on stature within the sport.

2.2.1.2 Stature

Similar positional trends have been reported for player stature to those observed for body mass. In research examining the anthropometric attributes of male basketball players, both Parr et al. (1978) (G: 188.0 ± 10.3 cm; F: 200.6 ± 5.0 cm; C: 214.0 ± 5.2 cm) and Latin et al. (1994) (G: 187.4 ± 5.8 cm; F: 198.4 ± 3.8 cm; C: 205.5 ± 6.1 cm) reported centres to be taller than forwards and guards, and forwards to be taller than guards within American competitions. In elite Australian male basketball players, McInnes and colleagues (1995) reported similar positional stature differences with guards observed to be shorter (180.8 ± 10.2 cm) than forwards and centres (197.1 ± 2.0 cm).
These trends have also been observed in more recent research examining European male players. Apostolidis et al. (2003) (G: 193.8 ± 2.5 cm; F: 203.3 ± 4.0 cm; C: 206.0 ± 2.0 cm), Sallet et al. (2005) (G: 185.7 ± 6.9 cm; F: 195.8 ± 4.8 cm; C: 203.9 ± 5.3 cm), and Ostojic et al. (2006) (G: 190.7 ± 6.0 cm; F: 195.8 ± 4.8 cm; C: 203.9 ± 5.3 cm) observed centres to be taller than forwards and guards, and forwards to be taller than guards within elite Greek, French, and Serbian male basketball competitions. In addition, Cormery et al. (2008) and Ben Abdelkrim et al. (2007) reported comparable positional differences in national French (G: 184 ± 2 cm; F: 200 ± 1 cm; C: 208 ± 3 cm) and Tunisian male players (G: 183 ± 4 cm; F: 188 ± 4 cm; C: 193 ± 3 cm).

Similar to the observations and assumptions made for body mass, the reported positional differences in stature can largely be attributed to the demands placed on each position during competition, with centres and forwards needing greater stature for match activities such as rebounding and contesting shots. Thus, player stature may also be a decisive factor in assigning positional roles during player selection processes. While strong trends are evident for both body mass and stature within male basketball players, other anthropometric measures, such as body composition, do not display these patterns.

2.2.1.3 Body Composition

While some positional trends are evident for body composition measures within male basketball players, they are not as pronounced as those reported for body mass and stature. In early research by Latin and colleagues (1994), centres (11.2 ± 4.5%) possessed a greater percent body fat (%BF) than both forwards (9.7 ± 3.9%) and guards (8.4 ± 3.0%) in collegiate American male basketball players. More recently, similar positional differences in body composition were reported for elite Greek (G: 10.3 ± 1.7%; F: 11.8 ± 0.7%; C: 13.1 ± 2.2%) (Apostolidis et al. 2003), French (G: 13.5 ± 0.9%; F: 13.6 ± 0.6%; C: 14.9 ± 1.3%) (Cormery et al. 2008), and Serbian male players (G: 9.9 ± 3.1%; F: 10.1 ± 3.2%; C: 14.4 ± 5.6%) (Ostojic et al. 2006). These results suggest that the physical requirements of guards and forwards may be more similar than reported body mass and stature data indicate. Furthermore, differences in positional roles may also explain these body composition trends, with physical
size possibly of greater importance for centres, and mobility and physical fitness more heavily relied upon in guard and forward positions during matches.

Compared to body mass and stature, there is relatively little positional variation in the body compositions of male basketball players within the existing literature. Furthermore, %BF has been reported to be negatively correlated with the performance of elite basketball players during a number of field tests (Apostolidis et al. 2003). This supports the general consensus that excess or unnecessary body fat is detrimental to athletic performance during weight bearing activity, including basketball (Apostolidis et al. 2003). As such, measurements of %BF in basketball players may provide an indication of the demands experienced during competition.

Existing research examining the anthropometric characteristics of male basketball players identifies some strong positional trends. The trends reported for stature, body mass, and body composition may reflect positional match demands. Furthermore, some of these characteristics, such as stature and body mass, may determine or increase the likelihood of a particular player occupying a specific positional role (Ostojic et al. 2006). The wide ranges evident within these data also indicate that these attributes may not be a definitive requirement for players to compete at an elite level. Ostojic and colleagues (2006) highlighted the importance of individual skills and team cohesion in basketball competition, downplaying the role of optimal anthropometric characteristics for successful performance. Whilst the provision of anthropometric data allows assumptions to be made concerning basketball match demands, the added measurement of fitness characteristics within players provides further insight.

2.2.2 Physiological Fitness Data

Determination of fitness characteristics in basketball players provides an indirect measurement of the demands experienced during matches. The most readily investigated fitness characteristics measured within male basketball players include vertical jump (VJ) and sprint ability, as well as anaerobic and aerobic capacities (Apostolidis et al. 2003; Balcıunas et al. 2006; Ben Abdelkrim et al. 2010a, 2010b, 2010c, 2007; Carvalho et al. 2011;
Vertical Jump Performance

Jumping actions are regularly performed by basketball players during matches (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Furthermore, VJ ability has been documented to be significantly related (r = 0.68) to playing time in collegiate basketball competition (Hoffman et al. 1996a). Thus, VJ performance may be considered a key activity component of basketball match play.

Research investigating jumping ability in basketball players has mostly utilised countermovement (CMJ) or squat jump (SQ) techniques. Countermovement jumping techniques typically involve a single step backwards prior to flexing at the hips and bending at the knees and jumping off both legs (Drinkwater et al. 2007). In contrast, SJ methods generally involve the feet being stationary and jumping from a bent-knee squat position off both legs (Balciunas et al. 2006). Previously, CMJ has been observed to produce greater PO due to the superior elastic energy stored within the leg musculature during the eccentric and concentric phases of the jump (Benche et al. 2002; Bobbert, Gerritsen, Litjens & Van Soest, 1996). Researchers investigating the jumping ability of male basketball players have reported varied responses between and within different regions using both CMJ and SJ methodologies (Apostolidis et al. 2003; Balciunas et al. 2006; Ben Abdelkrim et al. 2010c; Castagna et al. 2009; Chaouachi et al. 2009; Drinkwater et al. 2007; Greene et al. 1998; Laplaud et al. 2004; Latin et al. 1994; Montgomery et al. 2008a; Ostojic et al. 2006).
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Positions</th>
<th>Vertical Jump</th>
<th>Anaerobic Performance</th>
<th>Threshold</th>
<th>VO_{max} (ml\cdot kg^{-1}\cdot min^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 40.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>CMJ 38.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 39.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>CMJ 41.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 42.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>CMJ 44.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 45.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>CMJ 47.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 48.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>CMJ 49.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sanford et al. (2006)</td>
<td>All players (n = 24)</td>
<td>All players</td>
<td>SJ 50.0 ± 2.0</td>
<td>80 m sprint (s) 4.1 ± 0.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2.2: A summary of existing research describing the fitness characteristics of male basketball players.
<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Study</th>
<th>Location</th>
<th>Sample Size</th>
<th>Variables</th>
<th>Values (Mean ± SD)</th>
<th>Additional Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castagna et al. (2007)</td>
<td>Competitive</td>
<td>Italian Junior All</td>
<td>n = 18</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Castagna et al. (2010)</td>
<td>Regional</td>
<td>Italian Junior All</td>
<td>n = 14</td>
<td>N/A</td>
<td>AnT (%HRmax)</td>
<td>84 ± 5.1</td>
</tr>
<tr>
<td>Caterisano et al. (1995)</td>
<td>Collegiate</td>
<td>US All</td>
<td>n = 9</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Chaouachi et al. (2009)</td>
<td>International</td>
<td>Tunisian All</td>
<td>n = 14</td>
<td>CMJ</td>
<td>61.9 ± 6.2, 49.5 ± 4.8</td>
<td>5 m sprint (s) 0.82 ± 0.05, 10 m sprint (s) 1.70 ± 0.06</td>
</tr>
<tr>
<td>Cook et al. (2004)</td>
<td>Elite Junior</td>
<td>Australian All</td>
<td>n = 38</td>
<td>CMJ</td>
<td>62.0 ± 6.7</td>
<td>N/A</td>
</tr>
<tr>
<td>Cormery et al. (2008)</td>
<td>National</td>
<td>French Guards</td>
<td>n = 10</td>
<td>N/A</td>
<td>VT (%HRmax)</td>
<td>85.8</td>
</tr>
<tr>
<td>Cormery et al. (2008)</td>
<td>National</td>
<td>French Forwards</td>
<td>n = 19</td>
<td>N/A</td>
<td></td>
<td>86.6</td>
</tr>
<tr>
<td>Cormery et al. (2008)</td>
<td>National</td>
<td>French Centres</td>
<td>n = 8</td>
<td>N/A</td>
<td></td>
<td>82.0</td>
</tr>
<tr>
<td>Delestrat &amp; Cohen (2008)</td>
<td>University</td>
<td>First/Second Teams</td>
<td>n = 8</td>
<td>CMJ</td>
<td>56.6 ± 4.4, 51.6 ± 3.3</td>
<td>20 m sprint (s) 3.29 ± 0.12, 3.36 ± 0.36</td>
</tr>
<tr>
<td>Drinkwater et al. (2007)</td>
<td>National/State</td>
<td>Australian Nat/State</td>
<td>n = 129</td>
<td>CMJ</td>
<td>62.0 ± 8.4, 59.1 ± 7.3</td>
<td>20 m sprint (s) 3.08 ± 0.13, 3.15 ± 0.16</td>
</tr>
<tr>
<td>Drinkwater et al. (2007)</td>
<td>National</td>
<td>Polish All</td>
<td>n = 54</td>
<td>N/A</td>
<td>Peak power (W·kg⁻¹) 11.1 ± 0.8, Mean power (W·kg⁻¹) 8.7 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Goentas et al. (2007)</td>
<td>International</td>
<td>European All</td>
<td>n = 33</td>
<td>N/A</td>
<td>AnT (%HRmax)</td>
<td>72.1</td>
</tr>
<tr>
<td>Greene et al. (1998)</td>
<td>High-School</td>
<td>US All</td>
<td>n = 61</td>
<td>SJ</td>
<td>64.0 ±10.8</td>
<td>N/A</td>
</tr>
<tr>
<td>Hoffman et al. (1999)</td>
<td>National</td>
<td>Israeli All</td>
<td>n = 20</td>
<td>N/A</td>
<td>Peak power (W·kg⁻¹) 14.4 ± 1.7, Mean power (W·kg⁻¹) 9.1 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>Kalinski et al. (2002)</td>
<td>National</td>
<td>Polish All</td>
<td>n = 54</td>
<td>N/A</td>
<td>Peak power (W·kg⁻¹) 11.1 ± 0.8, Mean power (W·kg⁻¹) 8.7 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Laplaud et al. (2004)</td>
<td>National</td>
<td>French All</td>
<td>n = 8</td>
<td>CMJ</td>
<td>62 ± 8</td>
<td>VT (%HRmax) 75.5</td>
</tr>
<tr>
<td>Latin et al. (1994)</td>
<td>Collegiate</td>
<td>US Guards</td>
<td>n = 152</td>
<td>N/A</td>
<td>73.4 ± 9.6</td>
<td>N/A</td>
</tr>
<tr>
<td>Latin et al. (1994)</td>
<td>Collegiate</td>
<td>US Forwards</td>
<td>n = 124</td>
<td>N/A</td>
<td>71.4 ± 10.4</td>
<td>N/A</td>
</tr>
<tr>
<td>Latin et al. (1994)</td>
<td>Collegiate</td>
<td>US Centres</td>
<td>n = 73</td>
<td>N/A</td>
<td>66.8 ± 10.7</td>
<td>N/A</td>
</tr>
<tr>
<td>Study Reference</td>
<td>Location</td>
<td>Sample Description</td>
<td>Measures</td>
<td>Data Mean ± SD</td>
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<td></td>
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<tr>
<td>-------------------------</td>
<td>-------------------</td>
<td>-----------------------------------------</td>
<td>-----------------------------------</td>
<td>-------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McInnes et al. (1995)</td>
<td>Nat Australian</td>
<td>Guards (n = 3) Frontcourt (n = 5) All (n = 8)</td>
<td>N/A N/A N/A</td>
<td>N/A 65.5 ± 4.5 57.8 ± 9.5 60.7 ± 8.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metaxas et al. (2009)</td>
<td>Nat Greek</td>
<td>Division I (n = 14) Division II (n = 15) Division III (n = 17) Division IV (n = 15)</td>
<td>N/A N/A AnT (%HRmax)</td>
<td>86.2 82.7 82.5 84.9 51.3 ± 4.0 50.4 ± 5.4 47.8 ± 5.3 49.1 ± 5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Montgomery et al. (2008a)</td>
<td>Elite Junior Australian</td>
<td>All (n = 29)</td>
<td>N/A 61.9 ± 14.6</td>
<td>20 m sprint (s) 3.09 ± 0.10 N/A</td>
<td>N/A 68.6 ± 1.3</td>
<td></td>
</tr>
<tr>
<td>Montgomery et al. (2010)</td>
<td>Elite Junior Australian</td>
<td>All (n = 11)</td>
<td>N/A N/A</td>
<td></td>
<td>N/A 57.5 ± 8.2</td>
<td></td>
</tr>
<tr>
<td>Narazaki et al. (2009)</td>
<td>Collegiate US</td>
<td>All (n = 6)</td>
<td>N/A N/A</td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Ostojic et al. (2006)</td>
<td>Nat Serbian</td>
<td>Guards (n = 20) Forwards (n = 20) Centres (n = 20) All (n = 60)</td>
<td>SJ 59.7 ± 9.6 57.8 ± 6.5 54.6 ± 6.9 57.4 ± 7.7</td>
<td>N/A N/A 52.5 ± 4.8 50.7 ± 2.3 46.3 ± 4.9 49.8 ± 4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parr et al. (1978)</td>
<td>Nat US</td>
<td>Guards Forwards Centres</td>
<td>N/A N/A</td>
<td>N/A 50.0 ± 5.4 45.9 ± 4.3 41.9 ± 4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sallet et al. (2005)</td>
<td>First/Second Division French</td>
<td>Combined Guards (n = 14) Forwards (n = 22) Centres (n = 22) First All (n = 33) Second All (n = 25)</td>
<td>N/A Peak power (W·kg⁻¹) Fatigue index (%)</td>
<td>13.1 ± 1.7 12.7 ± 3.5 11.2 ± 2.1 12.5 ± 0.3 11.9 ± 2.4 13.5 ± 1.7 12.6 ± 3.5 11.1 ± 2.1 12.5 ± 0.3 11.9 ± 2.4 93.5 92.6 94.8 94.4 93.8 93.5 57.5 ± 9.2 55.2 ± 6.5 52.9 ± 6.2 53.7 ± 6.7 56.5 ± 7.7 57.5 ± 9.2 55.2 ± 6.5 52.9 ± 6.2 53.7 ± 6.7 56.5 ± 7.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tavino et al. (1995)</td>
<td>Nat Brazilian</td>
<td>All (n = 9)</td>
<td>N/A N/A</td>
<td>N/A 65.2 ± 6.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

US = United States; Int = International; Nat = National; All = All players; CMJ = Countermovement jump; SJ = Squat jump; %HRmax = Relative heart rate; %Speedmax = Relative speed; VT = Ventilatory threshold; AnT = Anaerobic threshold; VO2max = Maximal oxygen consumption; N/A = Data not available.
Countermovement jump heights of 40.1-61.9 cm have been reported for European male players, suggesting that the lower-body power characteristics within European competition may vary according to the training plans adopted by individual teams. Less variation has been reported in Australian male basketball competition (59.1-62.0 cm) (Cook et al. 2004; Drinkwater et al. 2007; Montgomery et al. 2008b). However, this is likely due to the limited available data for these players. Similar trends have been reported for SQ ability, with considerable variations observed within European male players (39.8-57.4 cm) (Apostolidis et al. 2003; Balciunas et al. 2006; Castagna et al. 2009; Chaouachi et al. 2009; Ostojic et al. 2006). Only one known study has investigated the SQ ability of American male players, with a mean jump height of 64.0 ± 10.8 cm reported (Greene et al. 1998). Taken together, these results highlight the discrepancies in VJ performance between and within competitions around the world, and suggest that the lower-body power properties of male basketball players may be more strongly related to team factors as opposed to playing regions. Moreover, factors such as methodological differences and time of testing during the season must also be considered when interpreting these results.

When examined according to playing position, guards and forwards have possessed greater jumping ability than centres in male basketball competition. Previously, European (G: 59.7 ± 9.6 cm; F: 57.8 ± 6.5 cm; C: 54.6 ± 6.9 cm) (Ostojic et al. 2006) and American (G: 73.4 ± 9.6 cm; F: 71.4 ± 10.4 cm; C: 66.8 ± 10.7 cm) (Latin et al. 1994) male guards and forwards have been observed to hold a superior VJ performance compared with centres. These differences may be reflective of anthropometric attributes such as body composition. Guards and forwards have frequently been reported to possess lower %BF than centres (see Table 2.1), which has been reported to be directly related to VJ performance (Miller, White, Kinley, Congleton & Clark, 2002; Sipilä et al. 2004).

Whilst the assessment of VJ performance provides an indication of the lower-body power evident within basketball players, other power-based measures have also been frequently measured. One such measure is sprint performance, and it has previously been reported to
be an important component of match activity and significantly related to playing time in male basketball competition (Ben Abdelkrim et al. 2007; Hoffman et al. 1996a).

### 2.2.2.2 Sprint Performance

Recently, sprinting activity has been reported to contribute up to 6% of playing time within competitive male basketball matches (Ben Abdelkrim et al. 2010a). Sprinting bouts during competition are thought to cover reasonably short distances considering the small playing area encountered in basketball (~28 m x 15 m). As such, measurement of sprint performance over relevant distances within basketball players may provide a measurement of anaerobic power specific to competition activity. Previously, many researchers have reported the sprint performance of male basketball players (Apostolidis et al. 2003; Ben Abdelkrim et al. 2010b, 2010c; Chaouachi et al. 2009; Cook et al. 2004; Delextrat & Cohen, 2008; Drinkwater et al. 2007; Greene et al. 1998; Latin et al. 1994).

The majority of existing literature has reported on the sprint performance of European male players. Sprint times over 5 m (0.82-1.22 s), 10 m (1.70-2.08 s), 20 m (2.96-3.36 s), 28 m (4.2 ± 0.2 s), and 30 m (4.10-4.31 s) have been documented in European male players taken from various competitions (Apostolidis et al. 2003; Ben Abdelkrim et al. 2010b, 2010c; Chaouachi et al. 2009; Delextrat & Cohen, 2008). Less data is available for Australian and American male players, with comparable responses to European players being observed over distances of 10 m (1.76 ± 0.07 s), 18.3 m (3.13 ± 0.21 s), 20 m (3.08-3.15 s), 27.4 m (3.68-3.97 s), and 36.6 m (4.68-4.97 s) (Cook et al. 2004; Drinkwater et al. 2007; Greene et al. 1998; Latin et al. 1994). When interpreting these findings, some major positional discrepancies in sprint performance have been observed within male basketball players. Guards have possessed the greatest anaerobic power, followed by forwards, and then centres, as indicated by shorter sprint times over varied distances.

Previously, collegiate American male guards and forwards have outsprinted centres over 27.4 m (G: 3.68 ± 0.14 s; F: 3.83 ± 0.16 s; C: 3.97 ± 0.21 s) and 36.6 m (G: 4.68 ± 0.20 s; F: 4.84 ± 0.29 s; C: 4.97 ± 0.21 s) (Latin et al. 1994). The positional similarities between VJ and sprint performance can be expected, considering the strong relationships previously
observed between these measures in basketball players (Chaouachi et al. 2009). Furthermore, both jumping and sprint activity rely extensively on similar movement patterns and the stored elastic energy within the leg musculature during stretch-shortening processes (Kale, Asçi, Bayrak & Açikada, 2009). Positional differences in physical attributes, training plans, and competition demands may influence the muscular adaptations and biomechanical techniques necessary for jump and sprint activity, and possibly explain the greater performance of guards and forwards compared with centres.

The importance of explosive lower-body power properties during basketball competition has been frequently documented (Chaouachi et al. 2009; Delextrat & Cohen, 2008). However, short-term performance relying extensively on the lactic energy system has also been suggested to be an important component of basketball competition (Ben Abdelkrim et al. 2007; McInnes et al. 1995). As such, the anaerobic capacity of male basketball players has been widely investigated.

2.2.2.3 Anaerobic Capacity

To assess the anaerobic capacity of male basketball players, researchers have typically employed the 30 s Wingate test (Apostolidis et al. 2003; Carvalho et al. 2011; Delextrat & Cohen, 2009; Hoffman et al. 1999; Kalinski et al. 2002; Sallet et al. 2005). The Wingate test is laboratory-based and involves a 30-s all-out sprint on a cycle ergometer with the main performance measures collected being peak power (PP), mean power (MP), and fatigue (Hoffman, Epstein, Einbinder & Weinstein, 2000). While the specificity of this test to the muscle activation and movement patterns of basketball competition is extremely limited, no known basketball-specific protocols have gained widespread acceptance as a criterion anaerobic performance test (Hoffman et al. 2000).

Previously, distinct age-related differences have been observed in Wingate test performance within male basketball players. Elite open-age European male players have been observed to produce relative PP measures of 11.1-14.4 W·kg⁻¹, MP outputs of 8.7-9.1 W·kg⁻¹, and fatigue index scores of 56.3-63.8% (Hoffman et al. 1999; Kalinski et al. 2002; Sallet et al. 2005). Conversely, elite junior European male players have been reported
to possess lower relative power measures (PP: 9.4-10.7 W·kg⁻¹; MP: 8.0-8.1 W·kg⁻¹) and less fatigue (49.5 ± 20.4%) across a Wingate test than open-age players (Apostolidis et al. 2003; Carvalho et al. 2011). The observed age differences in anaerobic capacity may be explained by the frequently reported hormonal and neuromuscular changes that occur throughout the maturation period in males (Boisseau & Delamarche, 2000). As such, developments in neuromuscular activation, muscle mass, enzyme activities, and motor control may account for the superior anaerobic responses of open-age male basketball players (Mercier, Mercier, Granier, Le Gallais & Préfaut, 1992).

Similar positional differences have also been observed in Wingate test performance to that evident for VJ and sprint performance within male basketball players. Guards have possessed the greatest PO and fatigue responses compared with forwards and centres. Guards (13.1 ± 1.7 W·kg⁻¹) have produced greater (ES = 0.2) relative PP responses than forwards (12.7 ± 3.5 W·kg⁻¹) and centres (12.7 ± 3.5 W·kg⁻¹) within French male basketball competition (Sallet et al. 2005). Moreover, guards (63.8 ± 14.7%) have also exhibited greater (ES = 0.5) fatigue scores across the Wingate test than forwards (58.1 ± 9.3%) and centres (56.3 ± 15.7%) (Sallet et al. 2005). These results suggest that guards generate the greatest PO, but are unable to maintain it as effectively as forwards and centres across a 30-s high-intensity period. This could be a reflection of adaptations to match demands within guards as these positions have been observed to experience short bursts of explosive activity more frequently than forwards and centres (Ben Abdelkrim et al. 2007; McInnes et al. 1995).

Whilst several researchers have suggested that anaerobic capacity is the most important fitness component for basketball players (Latin et al. 1994; Ostojic et al. 2006; Tavino et al. 1995), many studies have also suggested aerobic fitness to be essential (Ben Abdelkrim et al. 2010b; Castagna et al. 2009; McInnes et al. 1995). The determination of aerobic performance properties within basketball players is warranted, considering that reliance upon both anaerobic and aerobic metabolic pathways occurs across matches (Ben Abdelkrim et al. 2007; McInnes et al. 1995).
2.2.2.4 Aerobic Capacity

Previously, basketball players have been suggested to utilise aerobic metabolism to a greater extent than anaerobic metabolism during competition (McInnes et al. 1995). Therefore, measures of aerobic performance such as ventilatory threshold (VT), anaerobic threshold (AnT), and VO$_{2\text{max}}$ may be key indicators of performance for basketball players. Previously, these measures have been reported for male basketball players from various competitions (Apostolidis et al. 2003; Ben Abdelkrim et al. 2010a, 2010b, 2010c, 2007; Castagna et al. 2010; Caterisano et al. 1997; Chaouachi et al. 2009; Cormery et al. 2008; Gocentus et al. 2005; Hoffman et al. 1999; Laplaud et al. 2004; Latin et al. 1994; McInnes et al. 1995; Metaxas et al. 2009; Montgomery et al. 2010; Narazaki et al. 2006; Ostojic et al. 2006; Parr et al. 1978; Sallet et al. 2005; Tavino et al. 1995).

Within existing research, varied VT and AnT values have been reported for male basketball players. Documented VT responses are only available for European basketball competition, with varied responses observed within national Greek and French male players (75.5-86.6 %HR$_{\text{max}}$) (Apostolidis et al. 2003; Cormery et al. 2008; Laplaud et al. 2004). Similarly, AnT has been observed to occur at different intensities within various European basketball competitions (72.1-86.2 %HR$_{\text{max}}$) (Castagna et al. 2010; Gocentus et al. 2005; Metaxas et al. 2009). These findings suggest that the reliance upon aerobic energetic pathways during match play may differ between basketball competitions.

Previously, AnT has been suggested to be a stronger indicator of aerobic performance than VO$_{2\text{max}}$ (Bishop, Jenkins & Mackinnon, 1998). As such, basketball players with higher AnT may be able to perform at higher work intensities prior to fatigue onset (Edwards, Clark & Macfadyen, 2003a). The reported discrepancies in AnT may be due to differences in the training regimes and match demands experienced within the investigated basketball players. As such, aerobic adaptations including shifts in substrate utilisation, increases in muscle buffering capacity, and enhancements in mitochondrial enzyme activity may be present within players completing greater training and match workloads (Burgomaster, Heigenhauser & Gibala, 2006; Edge, Bishop & Goodman, 2006; Gibala et al. 2006; Holloszy &
Coyle, 1984). However, more research is needed examining the threshold responses of male basketball players to gather a definitive consensus concerning the positional and playing level characteristics of this measure.

In contrast to the limited available threshold data, many studies have investigated the \( \dot{V}O_{2\text{max}} \) of male basketball players (see Table 2.2). As discussed, Australian and American male basketball players have been reported to possess greater \( \dot{V}O_{2\text{max}} \) than most European players. However, other factors such as competition level of the players also varied within these studies and may have impacted the findings considering that greater match demands and \( \dot{V}O_{2\text{max}} \) have been reported in higher playing standards (Ben Abdelkrim et al. 2010a, 2010c; Metaxas et al. 2009). Furthermore, various laboratory- and field-based methods have been used to assess \( \dot{V}O_{2\text{max}} \) within past studies and the related validity and measurement error reported for each of these should be acknowledged when interpreting existing findings.

In addition to the observed geographical discrepancies, positional differences in \( \dot{V}O_{2\text{max}} \) have also been reported. The majority of existing research has observed greater \( \dot{V}O_{2\text{max}} \) in guards (50.0-63.4 ml\( \cdot \)kg\(^{-1} \)\cdot min\(^{-1} \)) compared with forwards (45.2-55.2 ml\( \cdot \)kg\(^{-1} \)\cdot min\(^{-1} \)) and centres (41.9-52.9 ml\( \cdot \)kg\(^{-1} \)\cdot min\(^{-1} \)) within American and European male basketball players (Cormery et al. 2008; Ostojic et al. 2006; Parr et al. 1978; Sallet et al. 2005). However, some investigations have observed negligible positional differences in \( \dot{V}O_{2\text{max}} \) within other American and European male basketball competitions (Ben Abdelkrim et al. 2007; Latin et al. 1994). The reported positional variations suggest that position-specific aerobic fitness and match demands may vary between teams and competitions. Furthermore, guards possessing higher \( \dot{V}O_{2\text{max}} \) may experience the greatest aerobic demands across matches. Such activity loads have been reported to elicit aerobic adaptations in athletes including increased skeletal muscle capillarisation, enhanced mitochondrial mass, and improved fuel utilisation (Noakes, 2000).
In summary, research examining the fitness characteristics of basketball players suggests that reliance on various metabolic pathways for energy provision is encountered during match play. However, varied responses have been observed between regions, competitions, and playing positions, possibly due to differences in training loads and match requirements between players. To validate this suggestion, existing literature examining the physiological and activity demands of basketball competition must be discussed.

2.3 PHYSIOLOGICAL DEMANDS OF MALE BASKETBALL COMPETITION

Previously, the majority of research investigating basketball match demands has measured the physiological responses (HR, [BLA'], and \( \dot{V}O_2 \)) of male players (Ben Abdelkrim et al. 2010a, 2010b, 2009, 2007; McInnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008). A summary of previous studies describing the physiological responses of male basketball players during competition is presented in Table 2.3.

2.3.1 Heart Rate

The analysis of HR during team sports provides an indirect measurement of exercise intensity. Previously, HR responses of male basketball players have been readily measured during competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008). Male basketball players have experienced mean HR responses across matches ranging between 151-171 b∙min\(^{-1}\) or 80.1-94.4 %HR\(_{max}\) (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008). These large variations may be due to the type of competition being investigated, with lower responses previously reported during pre-season/practice matches (151-169 b∙min\(^{-1}\); 80.1-84.4 %HR\(_{max}\)) (McInnes et al. 1995; Narazaki et al. 2009; Vaquera Jimenez et al. 2008), compared to actual competition (162-171 b∙min\(^{-1}\); 89.0-94.4 %HR\(_{max}\)) (Ben Abdelkrim et al. 2010a, 2010b, 2007; Montgomery et al. 2010). Additionally, the aforementioned differences in aerobic fitness, as well as competition and environmental factors are also likely to influence the HR responses of players across matches.
Table 2.3: A summary of existing research describing the physiological responses of male basketball players during competition.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Positions</th>
<th>Heart Rate b·min⁻¹</th>
<th>%HR&lt;sub&gt;max&lt;/sub&gt;</th>
<th>Blood Lactate (mmol·L⁻¹)</th>
<th>Oxygen Consumption (VO₂) ml·kg⁻¹·min⁻¹</th>
<th>%VO₂&lt;sub&gt;max&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Abdelkrim et al. (2010a)</td>
<td>Int/Nat Junior Tunisian</td>
<td>Int (n = 16) Nat (n = 22)</td>
<td>N/A</td>
<td>94 ± 2</td>
<td>6.1 ± 1.1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>92 ± 2</td>
<td>5.0 ± 1.1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2010b)</td>
<td>Int/Nat Junior Tunisian</td>
<td>All (n = 18)</td>
<td>N/A</td>
<td>N/A</td>
<td>5.8 ± 1.1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>6.2 ± 1.3</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2007)</td>
<td>Nat Junior Tunisian</td>
<td>All (n = 38)</td>
<td>171 ± 4</td>
<td>91 ± 2</td>
<td>5.5 ± 1.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>McInnes et al. (1995)</td>
<td>Nat Australian</td>
<td>All (n = 8)</td>
<td>168 ± 9</td>
<td>89 ± 2</td>
<td>6.8 ± 2.8</td>
<td>8.5 ± 3.1</td>
<td>N/A</td>
</tr>
<tr>
<td>Montgomery et al. (2010)</td>
<td>Elite Junior Australian</td>
<td>All (n = 11)</td>
<td>162 ± 7</td>
<td>N/A</td>
<td>51.2 ± 3.4</td>
<td>70 ± 16</td>
<td>N/A</td>
</tr>
<tr>
<td>Narazaki et al. (2009)</td>
<td>Collegiate US</td>
<td>All (n = 6)</td>
<td>169 ± 5</td>
<td>N/A</td>
<td>4.2 ± 1.3</td>
<td>N/A</td>
<td>36.9 ± 2.6</td>
</tr>
<tr>
<td>Tessitore et al. (2006)</td>
<td>Competitive Senior Italian</td>
<td>All (n = 10)</td>
<td>N/A</td>
<td>N/A</td>
<td>3.7 ± 1.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Vaquera Jimenez et al. (2008)</td>
<td>Nat Spanish</td>
<td>Guards (n = 2)</td>
<td>163 ± 14</td>
<td>84</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Forwards (n = 3)</td>
<td>151 ± 10</td>
<td>80</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Centres (n = 3)</td>
<td>155 ± 9</td>
<td>82</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Int = International; Nat = National; All = All players; %HR<sub>max</sub> = Relative heart rate; %VO₂<sub>max</sub> = Relative oxygen consumption; N/A = Data not available.
When comparing match HR responses according to playing position, guards have worked at higher intensities in male competition (163 ± 14 b·min⁻¹; 84.4 %HR_max) compared with forwards (151 ± 10 b·min⁻¹; 80.1 %HR_max) and centres (155 ± 9 b·min⁻¹; 81.5 %HR_max) (Vaquera Jimenez et al. 2008). These trends suggest that the activity workloads placed on guards across matches may require greater effort than those placed on forwards and centres. Furthermore, these observations support the discussed differences in anthropometric and fitness parameters between playing positions evident for male basketball players.

The relatively high HR responses (>80 %HR_max) reported during basketball competition contradict the observations that HIA is performed between 6-20% of live match time (Ben Abdelkrim et al. 2010b, 2007; Bishop & Wright, 2006; McInnes et al. 1995). This discrepancy may be related to prolonged elevations in HR accompanying the large physiological cost of HIA. The dynamic nature of basketball competition allows only brief stoppages in play, which may not permit complete HR recovery (Vaquera Jimenez et al. 2008). Further, the increased HR responses may be due to the performance of upper-body activities during basketball competition (McInnes et al. 1995). Upper-body activities such as defensive pressure, rebounding, shooting, and passing are frequently performed in basketball and likely to contribute to the physiological load encountered during match play due to the added recruitment of upper-body musculature. Future research should account for these activities when reporting on the demands of basketball competition.

The measurement of HR responses across matches provides valuable physiological information to coaches, players, conditioning staff, and researchers. However, HR is influenced by other factors such as the nutritional status of players, environmental temperature, and exercise duration (Rodriguez-Alonso et al. 2003). As such, HR only provides an indirect estimation of match intensity. Consequently, to gather a more definitive indication of the physiological demands placed on players during competition, many researchers have also measured [BLa].
2.3.2 Blood Lactate Concentration

The measurement of [BLa] can give an indication of the predominant energy systems being utilised during match activity, especially in intermittent sports such as basketball (McLean, 1992). Blood lactate concentration is dependent upon the rate of lactate (La⁻) entry into, and removal from, the circulatory system, and therefore only provides an estimation of anaerobic involvement during exercise (Wilmore, Costill & Kenney, 2008). Furthermore, [BLa⁻] has been suggested to represent as low as one third of the concentration present in working muscles (Krstrup et al. 2006b), and to be directly indicative only of the activity performed directly before sample collection (Montgomery et al. 2010). Nevertheless, existing research describing the [BLa⁻] responses during basketball competition adds to the existing knowledge concerning basketball match demands.

In the first study to examine the blood lactate (BLa⁻) responses of elite basketball players during competition, McInnes et al. (1995) reported a mean [BLa⁻] of 6.8 ± 2.8 mmol∙L⁻¹ in elite Australian male players. More recently, lower [BLa⁻] have been observed in both American (4.2 ± 1.3 mmol∙L⁻¹) and European male competitions (3.7-6.1 mmol∙L⁻¹) (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006). It has been put forward that a number of variables may affect [BLa⁻] between and within matches. These include competition intensity, frequency and duration of breaks in play, and player physiological characteristics (McInnes et al. 1995). In addition, it has been suggested that during team sports, single samples of [BLa⁻] collected at different periods cannot be used to predict the metabolic demands for entire matches (Bangsbo, Norregaard & Thorso, 1991). Furthermore, variations between studies may be due to the type of competition being investigated, given that basketball practice activity has been reported to elicit lower [BLa⁻] than actual match activity (Montgomery et al. 2010).

Positional comparisons during male basketball competition demonstrate that guards work at intensities that elicit the highest [BLa⁻]. Previously, Ben Abdelkrim et al. (2007) reported significantly higher [BLa⁻] in guards (6.4 ± 1.2 mmol∙L⁻¹) compared with centres (4.9 ± 1.2 mmol∙L⁻¹) within elite junior Tunisian male basketball players. This strengthens the
previous suggestions that guards undertake greater movement intensities, and have a higher anaerobic energy demand throughout competition. Furthermore, the superior aerobic fitness evident within guard positions may allow faster replenishment of energy supplies and thus greater ability to repeatedly perform high-intensity bouts.

As suggested, a major limitation of BLa⁻ analysis to infer metabolic responses is the weak relationship between muscle lactate concentrations ([La⁻]) and [BLa⁻]. This difference is thought to result from faster clearance of La⁻ from the muscle than from the blood (Bangsbo et al. 1991; Krstrup et al. 2006b). For more conclusive evidence concerning [BLa⁻] during basketball competition, research needs to examine BLa⁻ responses more frequently from all active players across multiple matches.

In summary, the available [BLa⁻] data suggest that anaerobic metabolism plays an important role in energy production during basketball competition. Therefore, the development of appropriate training programs aimed at enhancing La⁻ tolerance may help to reduce intramuscular fatigue and improve playing performance. With this in mind, the aerobic component of basketball should not be underplayed as the oxidative responses of players may contribute to match performance through delaying the onset of anaerobic metabolism during HIA (Bangsbo et al. 2006).

2.3.3 Oxygen Consumption

Previously, it has been suggested that basketball competition may rely on aerobic metabolism for many functions, including phosphocreatine (PCr) restoration, maintenance of low-intensity activity (LIA) during matches, La⁻ disposal, and heat dissipation (Cormery et al. 2008). Therefore, VO₂ measurements may provide valuable information concerning the oxidative processes encountered during basketball competition. However, limited data exist on these responses (Montgomery et al. 2010; Narazaki et al. 2009).

Recently, Narazaki et al. (2009) examined the VO₂ responses of collegiate American basketball players during practice matches using a portable metabolic measurement system. Male players worked at 37.0 ± 2.4 ml·kg⁻¹·min⁻¹ (64.7 ± 7.0 %VO₂max) during match play. However, the VO₂ responses were only measured across a 20-min period and did not reflect
competition-specific durations (40-48 min). Furthermore, it is unlikely that players were able to compete at regular match intensities due to the bulky nature of the measurement equipment and also the lack of specificity regarding competition factors such as match importance, player motivation, and opponent ability. This assumption is supported with the relatively low [BLa'] observed across the practice competition (3.2-4.2 mmol·L⁻¹) compared to actual competition (6.8 mmol·L⁻¹) (McInnes et al. 1995; Narazaki et al. 2009).

More recently, Montgomery et al. (2010) estimated the VO₂ of elite Australian male basketball players using a specialised telemetry system with predictive software. Players worked at an intensity of 51.2 ± 3.4 ml·kg⁻¹·min⁻¹ (70 ± 16 %VO₂max) during the competitive matches. While these findings address the major limitations within the study by Narazaki et al. (2009), the use of HR measures within the predictive measurement system may have produced inflated VO₂ data. It was postulated that the HR responses accompanying static muscle contractions frequently performed during basketball activity, may have increased the estimated VO₂ measures (Montgomery et al. 2010). Nevertheless, it was concluded that aerobic energy pathways play an important role in competitive basketball activity (Montgomery et al. 2010). Given the limitations associated with measuring VO₂ responses during basketball competition, it may be difficult to definitively determine the precise contribution of aerobic metabolism during matches.

In summary, the available evidence concerning the physiological demands of basketball competition presents conflicting observations in identifying the predominant type of activity during competitive matches. Many researchers have emphasised the importance of anaerobic metabolism during basketball, as evidenced by the frequent reliance on the alactic and lactic energy systems (Ben Abdelkrim et al. 2007; Crisafulli et al. 2002; Hoffman et al. 1999; McInnes et al. 1995). This suggestion is supported by the relatively low VO₂max observed for elite basketball players compared with other intermittent team sports such as soccer (Chamari et al. 2004; Hoff, Wisloff, Engen, Kemi & Helgerud, 2002) and field hockey (Spencer et al. 2004). Furthermore, the relatively high [BLa'] observed during basketball competition suggest that anaerobic metabolism does play a major role in the sport (Ben
Abdelkrim et al. 2007; McInnes et al. 1995). However, aerobic activity has been reported to occupy the greatest proportion of match time in basketball, and players with greater aerobic fitness have been suggested to hold an advantage through the ability to perform at higher intensities before the onset of fatigue (Ben Abdelkrim et al. 2007; Ostojic et al. 2006). As such, to account for the overall activity demands of basketball competition, the contributions of both anaerobic and aerobic metabolism must be acknowledged.

Similar to anthropometric and fitness characteristics, investigation of the physiological responses of players during competition only provides an indirect assessment of match demands. Consequently, to gather more direct data, an increasing number of researchers have utilised TMA technologies to calculate the specific activity requirements of basketball competition.

### 2.4 ACTIVITY DEMANDS OF MALE BASKETBALL COMPETITION

Previously, TMA methodologies have been exclusively used to analyse the activity demands of basketball competition (Ben Abdelkrim et al. 2010a, 2010b, Bishop & Wright, 2006; Erculj et al. 2008; Janeira & Maia, 1998; Matthew & Delextrat, 2009; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). More specifically, video-based TMA has largely been utilised to examine basketball activity demands due to the limitations of global positioning system (GPS) technology including signal interference for indoor sports, the need to wear an attached receiver unit, and the relatively small sample rate (1 Hz) of these devices (Larsson, 2003). Additionally, GPS have displayed poor reliability in measuring player distances and speeds for high-intensity (CV = 11.2-32.4%) and very high-intensity running (CV = 11.5-30.4%) during team sport activities (Coutts & Duffield, 2010a; Duffield, Reid, Baker & Spratford, 2010). As such, to understand the existing research investigating basketball match activity demands, knowledge of the equipment, methodologies, and limitations of video-based TMA will now be detailed.
2.4.1 Time-motion Analysis in Team Sports

Time-motion analysis is a widely used method of measuring the match activity demands placed upon team sport athletes (Duthie, Pyne & Hooper, 2003). This approach has been regularly utilised to examine player movement patterns within many team sports including rugby league (Sirotic et al. 2009), soccer (Andersson et al. 2010; Barros, Valquer & Sant'Anna, 1999; Burgess et al. 2006; Drust, Reilly & Rienzi, 1998; Mohr et al. 2008), Australian Rules football (Dawson et al. 2004; Veale, Pearce & Carlson, 2007), rugby union (Deutsch, Kearney & Rehrer, 2007; Duthie, Pyne & Hooper, 2005), netball (Davidson & Trewartha, 2008), field hockey (Spencer et al. 2004), water polo (Platanou & Geladas, 2006), and futsal (Barbero-Alvarez et al. 2008). The majority of these studies have utilised video recordings and computer software, as video-based analysis is the ideal technique to use when performing TMA. Video-based methodologies appear to be the most accurate means of recording movement, allow researchers to include more sport-specific movement categories, and enable data to be re-analysed freely (Spencer et al. 2004). Furthermore, the data sampling rates commonly employed within video-based TMA methodologies (20-25 Hz) are considerably higher than those typically accompanying GPS technologies (1 Hz) (Ben Abdelkrim et al. 2007; Coutts & Duffield, 2010a; Duffield et al. 2010; Sirotic et al. 2009).

Typically, when using TMA within field-based team sports, one to seven cameras are positioned around the playing area. The major premise of camera positioning for this method is to have at least one camera placed at the halfway point of the field at an elevation of 3-20 m and a distance of 5-30 m from the sideline (Dobson & Keogh, 2007). When using video-based TMA within court-based team sports, a similar number of cameras can be used at an elevation of 1.5-5 m and a distance of 2-10 m from the sideline. These camera set-ups have been frequently utilised to capture all activities performed by team sport athletes across matches, consequently allowing the calculation of movement frequencies, durations, and distances (Dobson & Keogh, 2007).

While the above benefits of TMA support its use within team sports, a number of limitations are apparent with this technology. Firstly, the inherent subjective nature of TMA in team
sports creates the potential of acquiring unreliable and invalid data. There are often similarities between the movement categories devised in TMA research and often it is up to the researchers to subjectively categorise each observed activity. It has been suggested that each researcher’s interpretation of separate movement patterns will vary, consequently affecting the inter-observer reliability of TMA (Dobson & Keogh, 2007). Furthermore, most TMA studies have not reported inter-tester reliability. Therefore when comparing observations between studies, differences in movement categorisation are likely to be present (Dobson & Keogh, 2007). Secondly, within most TMA research, activity responses are described without acknowledging other factors such as athlete skill, decision-making, and team tactics (Dobson & Keogh, 2007). These elements may affect the activity patterns of players during competition, and if possible, research should account for them. Thirdly, most TMA studies are conducted on a group of players from the same team. However, the coaching, training programs, and consequently the match activity demands are likely to differ between teams within the same competition. Therefore, the observations made in such TMA studies may only be applicable to the investigated team and not be representative of the entire competition or sport. Subsequently, TMA research should aim to investigate players from various teams and competitions to gather more definitive match activity data for given sports. Finally, variation that exists between matches must also be considered when measuring team sport activity demands. Factors such as team tactics, opposition ability, and refereeing decisions may differ between matches and consequently affect player activity outputs (Deutsch et al. 2007). Therefore, team sport TMA methodologies should include multiple matches in order to attain the most valid representation of competition activity demands.

While these limitations have been identified within research examining various team sports, related and unique methodological issues specific to basketball TMA studies are evident. These issues largely pertain to differences in the movement categorisation and analysis, development of basketball-specific activity categories, and reported reliability and validity of previous research methodologies.
2.4.2 Movement Categorisation and Analysis in Basketball Research

To date, extensive variation exists in the development and analysis of movement categories between basketball TMA studies. Within TMA research, the match activities performed by team sport athletes are typically categorised into a pre-defined set of movement types (Dobson & Keogh, 2007). However, the development of various categories differ between studies, with some movements typically remaining consistent, including standing, walking, jogging, running and sprinting (Barbero-Alvarez et al. 2008; Dobson & Keogh, 2007; McInnes et al. 1995; Spencer et al. 2004).

A unique aspect of team sport TMA methodology is the development of movement categories for sport-specific activities. These categories can vary widely in their metabolic demands and movement patterns as they are usually developed according to specific skills or actions required within the investigated sport (Dobson & Keogh, 2007). Therefore, when developing TMA methodologies, researchers must have adequate knowledge of the specific movements required in the investigated sport to collect the most accurate and representative data possible (Dobson & Keogh, 2007). These issues are evident within existing basketball TMA literature, and more specifically relate to defining movement categories, performing movement analysis, developing basketball-specific activities, and using subjective analytical methodologies.

2.4.2.1 Detail of Movement Categorisation

Early research conducted by McInnes and colleagues (1995) examined the activity demands of basketball competition through the identification of several movement categories based on activity intensity (standing/walking, jogging, running, sprinting, specific, and jumping). Since this time, many basketball researchers have adopted this methodology when developing movement categories (Ben Abdelkrim et al. 2010a, 2010b, 2007; Matthew & Deletrat, 2009). However, other researchers have included broader activity categories (Bishop & Wright, 2006; Narazaki et al. 2009; Tessitore et al. 2006) or analysed overall activity (Erculj et al. 2008).
Recently, when investigating the activity demands of collegiate American basketball players during a practice match, Narazaki et al. (2009) only included four movement categories (standing, walking, running, and jumping). Similarly, Tessitore and colleagues (2006) included five movement categories (inactivity, walking, running, positioning, and jumping) when investigating the activity responses of senior Italian basketball players during a practice match. Using even less-specific movement categories, Bishop and Wright (2006) reported on the LIA, moderate-intensity activity (MIA), and HIA performed during elite British male basketball competition, and Erculj (2008) reported only the overall distance travelled by elite Slovenian basketball players during matches. The inclusion of broad movement categories does not provide the most detailed information concerning basketball match activity demands. The resultant data may not provide suitable detail to allow the development of valid conditioning programs or accurate assessment of player workloads across matches. Consequently, TMA studies investigating basketball match activity should adopt a similar methodology to that used by McInnes et al. (1995), as supported by most existing research.

2.4.2.2 Detail of Movement Analysis

Previously, the majority of existing basketball TMA research has reported on the durations players spend performing within each movement category (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). Furthermore, some studies have also included the calculation of movement frequencies to describe player activity across matches (Ben Abdelkrim et al. 2010a, 2007; Matthew & Delestrat, 2009; McInnes et al. 1995). While the provision of these data is regularly incorporated into basketball TMA research, only one recent study has measured movement-specific distance measures during basketball competition (Ben Abdelkrim et al. 2010b).

Ben Abdelkrim et al. (2010b) reported duration and distance data within each movement category across elite junior European male basketball matches. Previously, it has been suggested that due to the small playing area and the execution of various specific
movements (e.g. blocking, positioning, rebounding), the provision of distance data could underestimate the physical load placed on basketball players during competition (McInnes et al. 1995). However, it has since been argued that the additional acquisition of distance data may provide assistance to basketball coaches and conditioning staff in prescribing the most effective training plans (Ziv & Lidor, 2009). Thus, basketball TMA research should aim to describe movement frequencies, durations, and distances when analysing player activity. To date, no basketball TMA studies have provided this combined information.

2.4.2.3 Basketball-Specific Movements

Previous TMA research has frequently included movement categories specific to basketball activity (Ben Abdelkrim et al. 2010a; McInnes et al. 1995; Tessitore et al. 2006). Basketball-specific movement categories previously identified include positioning (offensive and defensive stances ready to act), shuffling (movement generally in a sideways or backward direction incorporating shuffling actions of the feet), and picks (screening actions of players) (Ben Abdelkrim et al. 2010a, 2007; McInnes et al. 1995). The inclusion of such categories within TMA studies is crucial in determining the precise competition demands, as often these types of movements impose a high metabolic cost to players (McInnes et al. 1995).

While recent basketball research has addressed the need to incorporate specific movement categories within TMA methodologies, no upper-body movements have been previously measured. Given that upper-body movements are involved in various activities performed during basketball competition, such as defending, rebounding, and shooting, it may be suggested that these movements can increase the physiological demands placed upon players. Previously, the additional recruitment of upper-body musculature has been observed to add to the overall metabolic cost of various activities (Hoffman, Kassay, Zeni & Clifford, 1996b). As such, previous research describing the activity demands of basketball competition may underestimate the total physical load imposed on players across matches. Therefore, to gain a complete understanding of the precise activity demands of basketball competition, a separate upper-body movement category should be included within basketball TMA studies.
Another important methodological issue evident within most basketball TMA research is the use of subjective classifications to measure player activity. Previously, many studies investigating basketball match activity demands have relied upon the subjective interpretation of researchers to classify player movements into different movement categories (Ben Abdelkrim et al. 2010a, 2007; Bishop & Wright, 2006; Matthew & Delextrat, 2009; McNnnes et al. 1995; Narazaki et al. 2009). Although the intra-tester reliability data reported for these subjective methodologies has been deemed acceptable (Ben Abdelkrim et al. 2007; Bishop & Wright, 2006; McNnnes et al. 1995; Narazaki et al. 2009), the inter-tester reliability data has only been presented within one study, and only for movement frequencies (Matthew & Delextrat, 2009). Therefore, due to the reliance upon individual interpretation, the use of subjective methodologies for activity categorisation may not be the most precise and accurate method available.

Often within subjective basketball TMA research, key terminology is employed, with the use of words such as ‘urgency’, ‘without urgency’, and ‘moderate urgency’ to distinguish between activity intensities (McInnes et al. 1995). As such, movement categorisation is reliant upon the subjective decision-making of the researcher(s) involved and therefore may not be viewed in a similar manner by other investigators. Despite this limitation, in some situations where specific movements performed within basketball are difficult to objectively quantify in terms of their intensity, such as jumping and positioning, subjectively describing movements may be the most practical method to apply.

Objective methodologies categorising player activity according to movement speed have been frequently utilised within research examining the match activity demands of other team sports such as soccer (Burgess et al. 2006), rugby union (Deutsch et al. 1998), and futsal (Barbero-Alvarez et al. 2008). Moreover, movement categorisation based on activity speed has demonstrated acceptable intra- and inter-tester reliability for frequency, duration, and distance data (Barbero-Alvarez et al. 2008; Burgess et al. 2006; Deutsch et al. 1998). To date, only one recent study has utilised this methodology within basketball (Ben Abdelkrim
Using objective analyses may counteract the error accompanying subjective techniques. However, a limitation of objective categorisation is the non-applicability of universal movement speeds to every athlete. For example, the maximum sprinting speed of one athlete may only be 24 km⋅hr⁻¹ and therefore be classified as running in most studies. However, the maximum sprinting speed of another athlete may be 26 km⋅hr⁻¹, which would fit the sprinting category in most studies. This may produce inaccuracies in the identification and calculation of activities performed during competition and should be acknowledged when interpreting objective basketball TMA data.

2.4.3 Type of Basketball Competition

While the methodological issues surrounding movement categorisation are important to recognise, another factor that should also be considered when interpreting existing basketball TMA research is the type of competition investigated. Previously, no research has described the activity demands experienced by open-age male basketball players during actual competitive matches. To date, the match activity demands of male basketball competitions have been described under superseded match rules (McInnes et al. 1995), within age-restricted competitions (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006), and during pres-season/practice matches (McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). These methodological differences should be considered when interpreting existing basketball TMA data.

McInnes et al. (1995) provided the first precise activity data for elite male basketball competition. However, these observations were made under the former match rules. Given the reported anthropometric and physiological differences reported for basketball players before and after the rule changes, it has been suggested that current basketball competition is likely to elicit greater activity requirements than previous competition (Cormery et al. 2008).

More recently, Ben Abdelkrim and colleagues (2010a, 2010b, 2007) examined the activity requirements of junior Tunisian male basketball competitions. However, considering the differences in the anthropometric and fitness characteristics reported between junior
(<18 yr) and open-age male basketball players (see Tables 2.1 and 2.2), variations in the activity requirements of these competitions are also likely to exist. Previously, open-age basketball players have been reported to be taller, have larger proportions of lean body mass, and possess greater anaerobic and aerobic fitness capacities than junior players (Ben Abdelkrim et al. 2010c; Carvalho et al. 2011; Greene et al. 1998; Sallet et al. 2005; Tavino et al. 1995; Vaquera Jimenez et al. 2008). Consequently, open-age male basketball competition may be played at higher intensities, with greater overall demands than junior competition.

Moreover, previous studies have also reported on basketball match activity demands during pre-season/practice matches (McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). Given that previous researchers have observed practice activity to elicit a lower physiological toll on players than actual matches (Montgomery et al. 2010; Rodriguez-Alonso et al. 2003), the results of these studies are not likely to be a true representation of competitive match demands. All of these factors should be considered when construing previous findings.

2.4.4 Reliability and Validity of Basketball Time-Motion Analysis Research

In addition to addressing movement categorisation and analytical issues, basketball TMA methodologies should be reliable and valid for the resultant data to be accurately applied to practical situations (Tong, Bell, Ball & Winter, 2001). Intra- and inter-tester reliability are vital in appreciating the sensitivity and usefulness of TMA methodologies. However, only intra-tester reliability has mostly been reported within basketball TMA studies (Ben Abdelkrim et al. 2010a; Bishop & Wright, 2006; Matthew & Delextrat, 2009; McInnes et al. 1995; Narazaki et al. 2009).

Typically, the determination of intra-tester reliability involves multiple analyses on the same piece of selected video footage by one researcher (Duthie et al. 2003). Originally, McInnes and colleagues (1995) determined the intra-tester reliability of frequency and duration data calculated during elite Australian male basketball matches. Reliability was determined using Intra-class Correlation Coefficient (ICC) and Coefficient of Variation (CV) statistics. The proportion of live time spent standing/walking possessed a moderate ICC (0.68), with all
other measures displaying high ICC (>0.80). It was suggested that the relatively low ICC observed for standing/walking may be due to the small range of values obtained within this category across all players. However, when interpreting the CV values, run (11.8%) and jog (11.1%) frequency, jump (11.7%), sprint (11.2%), and medium shuffle (10.9%) mean bout duration, and live time duration performing high-intensity shuffling (10.6%) possessed poor reliability (>10%) as per previous recommendations (Duthie et al. 2003).

More recently, Ben Abdelkrim et al. (2007) reported the intra-tester reliability when examining the match demands of elite junior Tunisian male basketball competition. Using CV analyses, good (CV <5%) reliability was reported for all frequency and duration data. The highest CV across all three measures was evident for high-intensity specific (3.1-3.9%) and sprinting activity (2.7-3.6%) (Ben Abdelkrim et al. 2007). Similarly, Bishop and Wright (2006) reported good reliability when investigating elite British male basketball competition, through the calculation of the relative Typical Error of Measurement (%TEM) for the proportion of match time spent performing LIA (0.6%), MIA (0.3%), and HIA (4.5%).

To date, only one study has reported the inter-tester reliability of basketball TMA methodology. Matthew and Delextrat (2009) reported good (CV <5%) reliability for activity frequencies within all movement categories during elite British female basketball matches. The highest CV were observed for running (3.9%), medium-intensity shuffling (3.3%), and sprinting activity (3.0%). Consequently, no inter-tester reliability data has been provided for duration or distance measures within basketball TMA research. Therefore, it is difficult to gather a definitive idea of the error present when multiple testers analyse basketball match activity demands using TMA. Nevertheless, it is apparent that more studies reporting on the intra- and inter-tester reliability of basketball TMA methodologies are needed.

The reliability values reported for basketball TMA are comparable to those observed in the methodologies of other team sports (Barbero-Alvarez et al. 2008; Deutsch et al. 1998; Duthie et al. 2003; Spencer et al. 2004). As such it is important to acknowledge that there is always inherent error involved in the use of video-based TMA methodologies. Therefore, the aim of researchers utilising this technology should be to reduce the amount of error.
involved as much as possible through developing suitable movement categories and sound procedures.

Whilst the above studies highlight the need for reliable TMA methodologies when measuring basketball match activity demands, the validity of these practices must also be considered. A major limitation of using TMA to analyse basketball match activity demands is the small sample sizes of players and matches often included (Dobson & Keogh, 2007). This creates a level of uncertainty within the findings and jeopardises the external validity of the research, as any conclusions made may be indicative of the team(s) investigated rather than of basketball in general. Furthermore, within each team, the playing demands are likely to differ from match to match as a consequence of varying playing conditions and opposition abilities (Dobson & Keogh, 2007). It has previously been suggested that to counteract this problem, researchers should increase the sample size of athletes and matches within their respective studies (Dobson & Keogh, 2007). However, it has also been acknowledged that this is impractical in most circumstances due to the extensive time required to gather and analyse data (Dobson & Keogh, 2007).

In summary, while some major methodological limitations are apparent within existing research investigating the activity demands of basketball competition, the previous observations should not be undervalued. Existing research describing the activity demands of basketball competition provides invaluable insight into the physical loads placed upon players during matches.

2.4.5 Match Activity Demands

In recent years, an increasing number of researchers have utilised TMA technologies to measure the activity demands of male basketball competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; McInnes et al. 1995; Narazaki et al. 2009). A summary of past studies examining basketball match activity demands is displayed in Table 2.4.
### Table 2.4: A summary of existing research describing the activity demands of male basketball competition.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Positions</th>
<th>Activity</th>
<th>Measure</th>
<th>Stand</th>
<th>Walk</th>
<th>Jog</th>
<th>Run</th>
<th>Stride</th>
<th>Sprint</th>
<th>Low Sp</th>
<th>Med Sp</th>
<th>High Sp</th>
<th>Jump</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Abdelkrim et al. (2010a)</td>
<td>Int/Nat Junior Tunisian</td>
<td>Int (n = 16)</td>
<td>Frequency</td>
<td>142 ± 14</td>
<td>152 ± 9</td>
<td>114 ± 7</td>
<td>78 ± 11</td>
<td>N/A</td>
<td>63 ± 17</td>
<td>164 ± 12</td>
<td>175 ± 37</td>
<td>94 ± 14</td>
<td>42 ± 7</td>
<td>1105 ± 74</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nat (n = 22)</td>
<td>Duration (%)</td>
<td>13.9 ± 2.1</td>
<td>14.2 ± 1.3</td>
<td>11.3 ± 0.6</td>
<td>10.2 ± 0.8</td>
<td>6.0 ± 1.0</td>
<td>13.6 ± 1.1</td>
<td>14.2 ± 4.1</td>
<td>9.3 ± 0.7</td>
<td>2.0 ± 0.4</td>
<td>-</td>
<td>1004 ± 27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Frequency</td>
<td>130 ± 9</td>
<td>125 ± 11</td>
<td>112 ± 10</td>
<td>96 ± 17</td>
<td>41 ± 22</td>
<td>163 ± 10</td>
<td>180 ± 12</td>
<td>74 ± 19</td>
<td>45 ± 7</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duration (%)</td>
<td>11.5 ± 2.7</td>
<td>13.4 ± 1.4</td>
<td>12.0 ± 0.9</td>
<td>11.2 ± 1.0</td>
<td>4.9 ± 1.2</td>
<td>14.2 ± 0.8</td>
<td>19.8 ± 4.0</td>
<td>8.1 ± 1.2</td>
<td>2.1 ± 0.3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2010b)</td>
<td>Int/Nat Junior Tunisian</td>
<td>All (n = 18)</td>
<td>Duration (%)</td>
<td>32.3 ± 1.4</td>
<td>31.0 ± 1.2</td>
<td>5.6 ± 0.5</td>
<td>4.5 ± 0.5</td>
<td>2.4 ± 0.5</td>
<td>2.8 ± 0.6</td>
<td>14.1 ± 1.0</td>
<td>11.0 ± 0.9</td>
<td>11.5 ± 1.0</td>
<td>1.3 ± 0.3</td>
<td>13.9 ± 2.1</td>
<td>7558 ± 575</td>
</tr>
<tr>
<td>Ben Abdelkrim et al. (2007)</td>
<td>Nat Junior Tunisian</td>
<td>Guards (n = 8)</td>
<td>Frequency</td>
<td>141 ± 15</td>
<td>130 ± 8</td>
<td>113 ± 8</td>
<td>103 ± 11</td>
<td>N/A</td>
<td>67 ± 5</td>
<td>176 ± 14</td>
<td>230 ± 37</td>
<td>104 ± 19</td>
<td>41 ± 7</td>
<td>1103 ± 32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forwards (n = 18)</td>
<td>Duration (%)</td>
<td>14.5 ± 1.2</td>
<td>13.9 ± 1.0</td>
<td>11.0 ± 0.5</td>
<td>10.2 ± 1.0</td>
<td>5.9 ± 0.7</td>
<td>13.4 ± 1.1</td>
<td>19.8 ± 2.3</td>
<td>9.3 ± 0.9</td>
<td>2.0 ± 0.4</td>
<td>-</td>
<td>1022 ± 45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centres (n = 12)</td>
<td>Frequency</td>
<td>149 ± 9</td>
<td>126 ± 15</td>
<td>110 ± 10</td>
<td>88 ± 5</td>
<td>56 ± 5</td>
<td>173 ± 6</td>
<td>186 ± 13</td>
<td>94 ± 13</td>
<td>41 ± 6</td>
<td>-</td>
<td>1026 ± 27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>All (n = 38)</td>
<td>Duration (%)</td>
<td>15.6 ± 0.6</td>
<td>14.0 ± 0.8</td>
<td>11.4 ± 0.7</td>
<td>10.1 ± 0.4</td>
<td>2.1 ± 0.1</td>
<td>14.4 ± 0.6</td>
<td>17.9 ± 2.0</td>
<td>9.2 ± 0.6</td>
<td>2.0 ± 0.3</td>
<td>-</td>
<td>1050 ± 51</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Frequency</td>
<td>150 ± 10</td>
<td>130 ± 8</td>
<td>117 ± 6</td>
<td>101 ± 19</td>
<td>43 ± 4</td>
<td>175 ± 11</td>
<td>176 ± 9</td>
<td>85 ± 8</td>
<td>49 ± 3</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duration (%)</td>
<td>16.4 ± 1.1</td>
<td>15.4 ± 0.8</td>
<td>12.4 ± 0.6</td>
<td>10.8 ± 0.9</td>
<td>2.2 ± 0.1</td>
<td>14.7 ± 1.0</td>
<td>15.5 ± 0.9</td>
<td>7.9 ± 0.8</td>
<td>2.3 ± 0.1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Frequency</td>
<td>147 ± 11</td>
<td>129 ± 10</td>
<td>113 ± 8</td>
<td>97 ± 14</td>
<td>55 ± 11</td>
<td>175 ± 10</td>
<td>197 ± 33</td>
<td>94 ± 16</td>
<td>44 ± 7</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duration (%)</td>
<td>15.5 ± 1.2</td>
<td>14.4 ± 1.1</td>
<td>12.4 ± 0.6</td>
<td>10.4 ± 0.8</td>
<td>2.1 ± 0.2</td>
<td>14.2 ± 1.0</td>
<td>17.7 ± 2.5</td>
<td>8.8 ± 1.0</td>
<td>2.1 ± 0.3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bishop &amp; Wright (2006)</td>
<td>British Nat</td>
<td>All (n = 6)</td>
<td>Duration (%)</td>
<td>52.5 ± 3.7</td>
<td>41.3 ± 3.5</td>
<td>6.1 ± 1.5</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Erculj et al. (2008)</td>
<td>Nat Slovenian</td>
<td>All (n = 23)</td>
<td>Distance (m)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4404 ± 354</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>McInnes et al. (1995)</td>
<td>Nat Australian</td>
<td>All (n = 8)</td>
<td>Frequency</td>
<td>295 ± 54</td>
<td>33.6</td>
<td>99 ± 36</td>
<td>11.3</td>
<td>107 ± 27</td>
<td>11.2</td>
<td>105 ± 52</td>
<td>168 ± 33</td>
<td>114 ± 44</td>
<td>63 ± 33</td>
<td>46 ± 12</td>
<td>997 ± 183</td>
</tr>
<tr>
<td>Narazaki et al. (2009)</td>
<td>Collegiate US</td>
<td>All (n = 12)</td>
<td>Frequency</td>
<td>22.8 ± 5.9</td>
<td>9.4</td>
<td>108.7 ± 9.2</td>
<td>56.9</td>
<td>N/A</td>
<td>78.2 ± 14.7</td>
<td>32.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>17.3 ± 8.4</td>
</tr>
<tr>
<td>Tessitore et al. (2006)</td>
<td>Senior Italian</td>
<td>All (n = 10)</td>
<td>Duration (%)</td>
<td>15</td>
<td>48</td>
<td>N/A</td>
<td>17</td>
<td>N/A</td>
<td>N/A</td>
<td>19</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Int = International; Nat = National; All = All players; Low Sp = Low-intensity specific movements; Med Sp = Medium-intensity specific movements; High Sp = High-intensity specific movements; LI A = Low-intensity activity; MIA = Moderate-intensity activity; HIA = High-intensity activity; N/A = Data not available.
In the first study to analyse the precise activity demands of basketball competition, McInnes and colleagues (1995) reported on the activity responses of elite Australian male basketball players. Players experienced a mean frequency of 997 ± 183 movements, with a mean duration of ~3 s per movement. Interestingly, a change in movement category occurred on average every ~2 s (McInnes et al. 1995). These data emphasise the highly intermittent nature of basketball, and suggest a need for extensive agility development within players due to the frequent requirement to accelerate, decelerate, and change direction. Furthermore, McInnes and colleagues (1995) reported that players spent 35%, 50%, and 15% of live time performing LIA (standing, walking, and low-shuffle), MIA (jog, run, and medium-shuffle), and HIA (sprint, jump, and high-shuffle). The relatively large contribution of HIA supports the observed mean [BLa] of 6.8 mmol·L⁻¹, which is considerably greater than concentrations typically reached at AnT. Despite these observed anaerobic demands, McInnes et al. (1995) suggested that HIA constitutes only a small proportion of match play, and most of live playing time is spent performing at lower intensities.

Recently, a greater quantity of data has been provided describing the activity demands of various basketball competitions. Ben Abdelkrim et al. (2010a, 2010b, 2007) examined the activity demands of a number of junior Tunisian male basketball competitions across multiple matches. On average, players performed 1050-1105 total movements during competition, with the mean duration of each movement not exceeding 3 s. Furthermore, players spent between 24.9-63.3%, 14.1-26.2%, 11.0-31.0%, and 11.5-20.3% performing recovery activity (standing, and walking), LIA (low-specific movements, and jogging), MIA (medium-specific movements, and running), and HIA (high-specific movements, sprinting, jumping, positioning, and setting picks) across competition. These large discrepancies in activity proportions are likely due to the provision of data relative to live time (time when ball is in play) versus total time (time spent on the court, including all stoppages except inter-quarter breaks). This should be considered when interpreting the individual results of any TMA study. Nevertheless, the observations of Ben Abdelkrim et al. (2010a, 2010b, 2007)
reinforce previous suggestions that basketball is highly intermittent in nature and stresses both anaerobic and aerobic metabolic pathways.

While the frequency and duration data reported relative to live time are mostly comparable between the studies of Ben Abdelkrim et al. (2010a, 2010b, 2007) and McInnes et al. (1995), some minor differences are apparent. Ben Abdelkrim et al. (2010a, 2010b, 2007) reported greater contributions of basketball-specific movements (shuffling and any foot action different from ordinary walking or running) than McInnes et al. (1995), with players spending up to 42% of live time performing these activities compared with the earlier observations of 35% made by McInnes et al. (1995). Furthermore, the junior Tunisian male players spent 16-20% of live match time performing HIA, which is greater than the 15% reported by McInnes et al. (1995) in open-age Australian male players. These differences may be explained by variations in the total time of the matches investigated. The analyses of Ben Abdelkrim et al. (2010a, 2010b, 2007) were conducted across 40-min matches, as opposed to 48-min matches used in the earlier study by McInnes et al. (1995). Differences in match time have been reported to affect the physiological and activity responses of players in other team sports, with longer match times showing a tendency for less intense activity across competition (Platanou & Geladas, 2006).

Positional variations in the activity demands of competition have also been reported within existing basketball research. Ben Abdelkrim et al. (2007) observed guards (17.1 ± 1.2%) and forwards (16.6 ± 0.8%) to spend significantly greater proportions of live time performing HIA compared with centres (14.7 ± 1.0%). Furthermore, guards (42.5%) appear to spend a greater proportion of live time performing basketball-specific movements than forwards (41.5%) and centres (38.1%). These observations further support the previously reported anthropometric and performance differences between positions and reinforce the suggestion that guards experience the greatest activity requirements across competition. These results also indicate that position-specific conditioning programs may be warranted.
While the majority of previous research has provided information on the frequencies and durations of basketball match activity, limited data exist detailing the court distances covered by players during competition (Ben Abdelkrim et al. 2010b; Erculj et al. 2008). Recently, Ben Abdelkrim et al. (2010b) reported on the distances travelled during total time within individual movement categories during elite junior Tunisian male basketball matches. Players covered a total of 7.56 ± 0.58 km, with 1.72 ± 0.14 km (23%), 2.45 ± 0.34 km (32%), 1.62 ± 0.28 km (21%), and 1.74 ± 0.32 km (24%) travelled performing recovery, LIA (0-12 km·h⁻¹), MIA (12-18 km·h⁻¹), and HIA (>18 km·h⁻¹). The total match distance observed by Ben Abdelkrim et al. (2010b) is less than that observed for other team sports such as soccer (Burgess et al. 2006; Stølen, Chamari, Castagna & Wisløff, 2005) and rugby union (Docherty, Wenger & Neary, 1988), even when analysis time is accounted for. The lower work rates observed in basketball players across matches have been suggested to be related to the smaller playing area not allowing as high speeds to be reached and maintained across competition compared to those observed in other team sports with larger playing surfaces (Ben Abdelkrim et al. 2010b).

It should be noted that when interpreting distance data, total match distance can be misleading. Previously, basketball-specific movements such as shuffling have been suggested to elicit a greater physiological load on players than typical running movements (McInnes et al. 1995). Similarly, running in backward and lateral directions have been observed to impose a higher metabolic cost than forward running (Reilly & Bowen, 1984; Williford, Olson, Gauger, Duey & Blessing, 1998). The frequent requirement to change direction during basketball matches also increases player demands due to the constant acceleration and deceleration actions (Dellal et al. 2010). As such, when reviewing existing research describing basketball match activity distances, the greater physiological stresses of shuffling, multidirectional, and intermittent movements should be acknowledged.

Only one other study has provided distance data for elite male basketball competition (Erculj et al. 2008) which reported on the total distance travelled during elite European male basketball matches. Erculj et al. (2008) utilised an extrapolation formula to estimate the
distance each player would travel across an entire match based on individual playing time. Players covered 4.40 ± 0.35 km per 40-min match. The large difference in total distances covered by players between the research conducted by Erculj et al. (2008) and Ben Abdelkrim et al. (2010b) may be due to the varied methodologies used. Erculj et al. (2008) provided distance data for players across live match time. In contrast, Ben Abdelkrim et al. (2010b) reported the distances travelled by players during total match time, including stoppages in play. Different analysis systems and techniques were also used to analyse player activity within these studies. Additionally, variations in player fitness, playing level, tactical decisions, match importance, and opposition ability may have contributed to the observed disparities between these findings.

While the existing body of research examining basketball match activity demands has grown in recent times, some researchers have only described the broad activity demands of basketball competition. Bishop and Wright (2006) reported the proportion of total time spent performing LIA (walking and standing) (52.5 ± 3.7%), MIA (jogging) (41.3 ± 3.5%), and HIA (sprinting, defensive shuffling, jumping, and positioning) (6.1 ± 1.5%) during open-age male basketball competition. These measures vary from previous basketball match activity observations, possibly due to differences in the classification of activity intensity. Bishop and Wright (2006) only categorised player activity into three movement categories, which is less specific than other methodologies (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995).

A limited number of movement categories have also been included within other basketball TMA studies. Recently, Narazaki et al. (2009) examined the activity demands of a 20-min practice match within collegiate American male and female basketball players. Activity was categorised as stand, walk, run, or jump, and basketball-specific movements such as shuffling and positioning, were not included in the analysis. It was reported that male players spent approximately 9% standing, 57% walking, 32% running, and 2% jumping, with few gender differences evident. Similarly, Tessitore et al. (2006) reported competitive senior (>50 yr) Italian male players to spend 15%, 48%, 17%, 19%, and 1% performing inactivity,
walking, running, positioning, and jumping across a 60-min practice match. These data vary slightly from that reported by Narazaki et al. (2009), with more inactivity, and less running and jumping observed in the senior players. However, comparisons are hard to make between these studies and other previous research given the differences in TMA methodology, movement interpretation, competition factors, and player populations examined.

Whilst the studies of Narazaki et al. (2009) and Tessitore et al. (2006) provide additional knowledge concerning the demands of basketball activity within specific populations, they are unlikely to validly reflect the demands experienced during actual competition. The examination of practice matches and the use of limited movement categories are major limitations of these earlier studies. Additionally, given the previously discussed gender differences in anthropometric and fitness characteristics of basketball players (see Tables 2.1 and 2.2), the inclusion of female participants in the study by Narazaki et al. (2009) further limits the applicability of these results to open-age male basketball competition.

With the increasing available data describing basketball match activity demands, more information has become available detailing the changes in match intensity across periods of play. The ability to maintain activity output across competition quarters has been suggested to be an important aspect of basketball performance (Montgomery et al. 2008a). As such, the determination of changes in movement intensity across match periods may provide additional detail on basketball competition demands, and allow more specific training plans and player management strategies to be implemented.

2.4.6 Intra-Match Activity Variation

The identification of variation in match play activity across playing periods has been suggested to provide valuable data for the management of athletes during team sport activity (Coutts et al. 2010b). Within basketball, tactical strategies and fatigue mechanisms have been suggested to reduce the activity intensity of players during subsequent match periods (Ben Abdelkrim et al. 2007; 2010b). However, equivocal observations have been made within existing research reporting on the intra-match activity variation within male
basketball competitions (Ben Abdelkrim et al. 2010a, 2010b, 2007; Janeira & Maia, 1998; McInnes et al. 1995). While some researchers have observed no changes in match activity demands across playing periods (McInnes et al. 1995, Matthew & Delextrat, 2009), others have reported reductions in activity workloads during the later stages of matches (Ben Abdelkrim et al. 2010a, 2010b, 2007; Janeira & Maia, 1998).

Janeira and Maia (1998) reported significantly decreased MIA, HIA, and jumping activity during the second half of elite male basketball matches compared to the first half. Similarly, data from Ben Abdelkrim et al. (2007) indicated a significant decline in HIA during the second (16.5 ± 1.6%) and fourth quarters (13.6 ± 1.3%) compared to the first (17.6 ± 1.8%) and third quarters (16.7 ± 1.4%), during national junior Tunisian basketball competition. Although muscle fatigue and glycogen depletion have been attributed to impaired work intensities in other intermittent team sports (Krustrup et al. 2006b; Mohr, Krustrup & Bangsbo, 2005), the decreases observed by Ben Abdelkrim et al. (2007) were suggested to be influenced by tactical strategies, including greater control of ball possession and reduced straight play and match pace.

Declines in HIA were also observed in more recent research by Ben Abdelkrim et al. (2010a; 2010b), with national junior Tunisian male basketball players performing significantly less HIA during the second (14.4 ± 1.1%) and fourth quarters (13.8 ± 1.5%) compared to the first (18.6 ± 0.9%) and third quarters (17.9 ± 1.8%). Additionally, international junior European players performed significantly less HIA only in the fourth quarter (16.8 ± 2.1%) compared to the third quarter (21.1 ± 2.4%) (Ben Abdelkrim et al. 2010a). Furthermore, Ben Abdelkrim et al. (2010b) observed national Tunisian male players to cover significantly less distance performing HIA (945 ± 195 vs. 798 ± 150 m) and significantly more distance performing LIA (1180 ± 168 vs. 1296 ± 219 m) during the second half of match play compared to the first half. It was suggested that many fatigue mechanisms may have contributed to the performance decrements across matches, including muscle glycogen depletion, temperature elevation, dehydration, and activity-induced muscle damage (Ben Abdelkrim et al. 2010a). Thus, the collective results of existing research suggest that both tactical factors
and fatigue mechanisms may affect player activity profiles across competition playing periods.

In recent times, greater research attention has been given to the activity demands, and subsequently the intra-match changes in activity profiles of male players during basketball competition. While this body of research provides a substantial knowledge base concerning the match activity demands imposed upon basketball players, major variations in the resultant data are evident. One factor that has frequently been suggested to contribute to these variations is the competition level of the players included. Previously the activity demands of athletes have been compared between competition levels within many team sports including rugby league (Sirotic et al. 2009), soccer (Mohr et al. 2003), and Australian Rules football (Brewer et al. 2010). To date, only one known study has directly compared the activity requirements and changes in activity demands of basketball players across matches between competition levels (Ben Abdelkrim et al. 2010a). Consequently, to gather a better understanding of the differences in match demands that exist between basketball playing levels, more research is warranted.

2.5 COMPETITION LEVEL DIFFERENCES IN MALE BASKETBALL

Basketball is played worldwide, with competition levels varying from amateur to elite. The available research suggests that differences may exist in the training loads, as well as the match demands experienced by players from different competition levels (Ben Abdelkrim et al. 2010c; Metaxas et al. 2009; Rodriguez-Alonso et al. 2003). It has been suggested that the examination of different standards of play can potentially limit how closely the gathered data reflect the actual demands of the investigated sport as a whole (Dobson & Keogh, 2007). Despite the awareness of this issue, few published studies have directly examined the differences in movement patterns between levels of competition within team sports (Brewer et al. 2010; Lupo, Tessitore, Minganti & Capranica, 2010; Mohr et al. 2008; Sirotic et al. 2009).
Applying TMA methodologies to different levels of basketball competition may identify any discrepancies between the match demands placed on elite and sub-elite players. This information may prove invaluable for lower-level players aspiring to compete at an elite level, through the development of more specific conditioning programs. Furthermore, these data may also assist basketball coaches, players, and support staff in identifying key physical performance elements that may differentiate standards of play (Dobson & Keogh, 2007). To date, the majority of the existing basketball literature has compared the anthropometric and fitness characteristics of male basketball players between competition levels (Ben Abdelkrim et al. 2010c; Delextrat & Cohen, 2008; Drinkwater et al. 2007; Metaxas et al. 2009; Sallet et al. 2005), with little research attention given to comparing physiological and activity demands during match play (Ben Abdelkrim et al. 2010a).

2.5.1 Anthropometric and Fitness Differences between Competition Levels

Within existing studies comparing the characteristics of male basketball players from different competition levels, researchers have reported on the anthropometric, sprint, AnT, and VO\textsubscript{2}\text{max} data. Furthermore, comparisons in these variables have only been provided for Australian and European basketball competitions.

Minor differences have largely been reported in the anthropometric characteristics of male players between competition levels (Ben Abdelkrim et al. 2010a, 2010c; Delextrat & Cohen, 2008; Drinkwater et al. 2007; Metaxas et al. 2009; Sallet et al. 2005). Previous research by Sallet et al. (2005) indicated a comparable body mass (93.9 ± 13.0 kg vs. 92.1 ± 13.6 kg), stature (197.0 ± 8.5 cm vs. 195.7 ± 9.6 cm), and %BF (12.7 ± 2.7% vs. 12.4 ± 3.7%) between adult male players competing within the first and second French basketball divisions. Similar observations have since been made in university first- (body mass: 90.6 ± 8.1 kg; stature: 192.4 ± 9.4 cm; %BF: 12.0 ± 5.0%) and second-team European male players (body mass: 86.0 ± 11.9 kg; stature: 187.2 ± 6.0 cm; %BF: 12.5 ± 4.7%) (Delextrat & Cohen, 2008), as well as adolescent national (body mass: 84.0 ± 10.3 kg; stature: 195 ± 9 cm; \text{7} skinfolds: 67.5 ± 20.6 mm) and state Australian male players (body mass: 77.3 ± 11.0 kg; stature: 188 ± 9 cm; \text{7} skinfolds: 68.4 ± 22.3 mm) (Drinkwater et al. 2007). More recently, Metaxas et al. (2009)
reported similar anthropometric measures for adult male basketball players competing within divisions I-IV of the national Greek league (body mass: 91.4-95.8 kg; stature: 1.90-1.93 m; %BF: 11.0-14.3%). Additionally, Ben Abdelkrim et al. (2010a) observed alike anthropometric characteristics within international (body mass: 81.2 ± 7.4 kg; stature: 1.88 ± 0.06 m; %BF: 6.4 ± 4.6%) and national junior Tunisian male basketball players (body mass: 79.6 ± 6.3 kg; stature: 1.89 ± 0.04 m; %BF: 9.6 ± 5.9%).

While small differences have been reported between competition levels in the physical characteristics of male basketball players, greater variations in the fitness properties of players have been observed between playing standards. Previously, Delextrat and Cohen (2008) reported university first-team European male basketball players to possess significantly greater VJH (56.6 ± 4.4 cm) compared with second-team players (51.6 ± 3.3 cm). First-team players (3.29 ± 0.12 s) also had faster 20 m sprint times than the second-team players (3.36 ± 0.36 s). Similarly, Drinkwater and colleagues (2007) reported that VJ (62.0 ± 8.4 cm vs. 59.1 ± 7.3 cm) and 20 m sprint performance (3.08 ± 0.13 s vs. 3.15 ± 0.16 s) were 78-88% likely to differ by a meaningful amount for national adolescent Australian male basketball players compared with state-level players. These findings suggest that explosive-type properties may be key fitness components for male basketball players competing at higher playing levels. However, it should be noted that limited research is available examining these characteristics between basketball playing levels, thus these trends may not be indicative of differences between other competitions.

In addition to short-term explosive measures, Sallet et al. (2005) compared anaerobic fitness capacities between male basketball competition levels using the 30 s Wingate test. First division French male players possessed higher PP (12.5 ± 3.0 W·kg⁻¹ vs. 11.9 ± 3.0 W·kg⁻¹), and significantly greater fatigue across the test (63.3 ± 13.8% vs. 54.1 ± 11.1%) than second division players. It is difficult to draw conclusions regarding the differences between basketball competition levels in anaerobic capacity based on these limited findings. However, these results resemble the trends discussed within existing VJ and sprint data for basketball players. As such, the ability to apply force rapidly, particularly within the lower-
body, may be an important fitness parameter differentiating elite male basketball players from sub-elite.

While distinct competition differences are evident within anaerobic fitness for male basketball players across competition levels, inconsistencies are apparent for aerobic indicators of performance. Within male basketball competition, elite European players have been reported to possess superior AnT and \( \dot{V}O_{2\text{max}} \) values compared with sub-elite players (Ben Abdelkrim et al. 2010a; Metaxas et al. 2009). Previously, players competing within the first division Greek national league have produced greater AnT work intensities (86.2 %HR\(_{\text{max}}\)) compared with division II (82.7 %HR\(_{\text{max}}\)), III (82.5 %HR\(_{\text{max}}\)), and IV players (84.9 %HR\(_{\text{max}}\)). Additionally, the first division Greek players also possessed significantly higher \( \dot{V}O_{2\text{max}} \) (51.3 ± 4.0 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)) than players from lower divisions (47.8-50.4 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)). Similarly, Ben Abdelkrim et al. (2010a) reported international junior Tunisian male players (54.4 ± 1.9 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)) to have significantly greater \( \dot{V}O_{2\text{max}} \) than national players (51.6 ± 2.0 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)). In contrast, Sallet et al. (2005) reported significantly greater \( \dot{V}O_{2\text{max}} \) values for second division French male players (56.5 ± 7.7 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)) compared with first division players (53.7 ± 6.7 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)). Taken together, these results strengthen previous suggestions that the oxidative energy system plays an important role across basketball match play (McInnes et al. 1995) and suggest that aerobic energy contribution during matches may vary between competitions.

In summary, small differences in the anthropometric data for male basketball players exist between competition levels. More pronounced differences have been observed within the fitness characteristics of players, indicating that natural ability, training load, and conditioning may be more dominant factors in differentiating the performance level of players compared with physical attributes. Furthermore, the observed differences in explosive, anaerobic, and aerobic measures between competition levels support existing match activity data indicating that metabolic contributions from the alactic, lactic, and oxidative energy systems are important during basketball competition. However, only assumptions can be made concerning the differences in match demands between basketball
competition levels using the available anthropometric and fitness data. As such, direct comparisons of the physiological and activity responses of basketball players during match play are needed to provide greater insight into variations in competition demands that may exist between playing levels.

2.5.2 Match Demand Differences between Competition Levels

To date, limited research has compared the physiological responses to match play between competition levels in male basketball players (Ben Abdelkrim et al. 2010a). Ben Abdelkrim et al. (2010a) reported HR and BLa measures within junior Tunisian male basketball players across six international and six national matches. International players exhibited significantly higher competition HR (94.4 ± 1.7 %HRmax) than national players (91.8 ± 2.2 %HRmax). Additionally, international players produced significantly greater mean [BLa] (6.12 ± 1.13 mmol∙L⁻¹) than national players (5.04 ± 1.14 mmol∙L⁻¹) during matches. These differences were suggested to reflect the activity demands of the international and national competitions, with the international players performing more HIA and recovery activities, and experiencing a greater intermittent workload. As such, the lower high-intensity demands and more continuous MIA evident within the national matches may have contributed to the lower HR and [BLa] measures observed within these lower-level players. Additionally, the superior aerobic fitness of the international players may have also contributed to the physiological differences evident between these competitions. However, to gather a greater understanding of the differences in the physiological responses of male players from various competition levels, more research is needed from various geographical regions.

Although physiological data provide insight into the match demands placed on basketball players, the aforementioned limitations of HR and BLa measures suggest that match activity data may describe competition level differences more precisely. To date, only one study has compared basketball match activity demands between playing levels (Ben Abdelkrim et al. 2010a). Recently, Ben Abdelkrim et al. (2010a) reported the activity requirements of international and national junior Tunisian male basketball competition. International players
performed significantly more total movements (1105 ± 74 vs. 1004 ± 27) and completed a significantly greater proportion of HIA (20.3 ± 2.1% vs. 16.2 ± 1.2%) during matches than national players. Furthermore, international players spent significantly less time performing MIA (24.4 ± 3.6% vs. 31.0 ± 3.9%) and significantly more time undergoing recovery actions such as standing and walking (28.1 ± 2.9% vs. 24.9 ± 3.2%) during competition.

Taken together, these findings suggest that elite basketball competition imposes a higher intermittent demand on players than sub-elite competition. As such, elite male basketball players may experience a greater requirement to accelerate, decelerate, and change direction during matches, which has been suggested to elicit an elevated metabolic cost to players (Dellal et al. 2010). Additionally, Ben Abdelkrim et al. (2010a) suggested that elite players possess a greater ability to perform repeated HIA than lower-level players, possibly due to longer passive recovery during competition and greater aerobic conditioning promoting faster restoration of energy substrates (Ben Abdelkrim et al. 2010a). Furthermore, these factors may explain the variations in intra-match activity demands observed by Ben Abdelkrim et al. (2010a).

Ben Abdelkrim et al. (2010a) observed national players to perform significantly less HIA during the second quarter (14.4 ± 0.1%) compared to the first quarter (18.6 ± 0.9%), and during the fourth quarter (13.8 ± 1.5%) compared to the third quarter (17.9 ± 1.8%). In contrast, international players were observed to only perform significantly less HIA during the fourth quarter (16.8 ± 2.1%) compared to the third quarter (21.1 ± 2.4%). The differences in the activity demands across matches between competition levels may have been due to the differences in passive recovery duration and player conditioning allowing repeated execution of high-intensity movements with adequate restoration of PCr and adenosine triphosphate (ATP) stores (Dupont, Blondel & Berthoin, 2003). However, tactical factors, such as increased control of ball possession and reduced court transitions were also suggested as contributors to the observed activity patterns across both the international and national matches (Ben Abdelkrim et al. 2010a).
The existing data describing differences in the activity demands between junior international and national Tunisian basketball competition are only representative of the European competitions investigated (Ben Abdelkrim et al. 2010a). Furthermore, this comparison has been made within junior players, and may not exemplify activity differences between open-age basketball competition levels. Thus, more research is needed to compare the match activity demands between open-age basketball playing levels.

Within the present review it has been established that previous TMA research investigating elite Australian male basketball competition has examined the activity of players during pre-season matches under now superseded game rules (McInnes et al. 1995). Furthermore, existing basketball TMA research within European and American competitions has examined the activity demands of age-restricted (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006) or practice competition (Narazaki et al. 2009; Tessitore et al. 2006), within female players (Matthew & Delextrat, 2009), and using non-specific movement categories (Bishop & Wright, 2006; Narazaki et al. 2009; Tessitore et al. 2006). Therefore, no known data exist that: (a) describe the current activity demands imposed upon Australian male basketball players during competition; (b) detail the precise match activity requirements of open-age male basketball competition; and (c) compare the current activity demands of elite and sub-elite open-age male basketball competitions.

The present thesis aims to address these research gaps. By providing these data, a number of practical benefits to basketball coaches, players, conditioning staff, and researchers will be developed within this thesis. One benefit is the potential development of a reliable and valid field test that simulates the current activity demands of open-age male basketball competition. Previously, simulation tests have been developed for a number of team sports. However, no such tests exist specific to basketball competition.
2.6 THE DEVELOPMENT OF TEAM SPORT SIMULATION TESTS

The majority of team sports encompass a range of movements that require athletes to possess explosive, anaerobic, and aerobic fitness. It is vital for team sport athletes to perform prolonged periodic LIA whilst still maintaining the ability to perform frequent bouts of HIA when required (Nicholas, Nuttall & Williams, 2000). However, the intensity, frequency, mean duration, and mean distance of these activity bouts vary between team sports (Barbero-Alvarez et al. 2008; Ben Abdelkrim et al. 2010a; Burgess et al. 2006; Dawson et al. 2004; Deutsch et al. 2007). Therefore, in order to develop accurate and valid team sport simulations, extensive data must first be gathered detailing the precise sport-specific match activity demands placed upon the competing athletes.

It has been suggested that athletes gain most benefit when a testing stimulus resembles or overloads the demands experienced during actual competition (Deutsch et al. 1998). However, many researchers have measured only elements of team sport activity in order to assess performance (Buchheit, Spencer & Ahmaidi, 2010; Oliver, Armstrong & Williams, 2007; Spencer, Bishop, Dawson & Goodman, 2005; Spencer, Fitzsimons, Dawson, Bishop & Goodman, 2006; Tan, Polglaze & Dawson, 2010; Wragg, Maxwell & Joust, 2000). Consequently, due to the acute nature of these methodologies and the non-specificity of the developed testing protocols to actual competition, the results of such studies generally do not provide an accurate description of team sport performance (Greenhaff, Hultman & Harris, 1993). To counteract these problems, many researchers have developed research protocols that simulate the actual activity demands of various team sport competitions (Bishop, Blannin, Robson, Walsh & Gleeson, 1999; Bishop, Spencer, Duffield & Lawrence, 2001; Drust, Cable & Reilly, 2000; Greig, McNaughton & Lovell, 2006; Higgins, Naughton & Burgess, 2009; Holloway, Meir, Brooks & Phillips, 2008; Mujika, McFadden, Hubbard, Royal & Hahn, 2006; Roberts, Stokes, Weston & Trewartha, 2010; Williams, Abt & Kilding, 2010; Williams et al. 2009).

There are many benefits in the development of team sport simulations compared with other less-specific performance tests. Firstly, researchers are able to replicate the demands of
actual competition more accurately which increases the external validity and practical application of the obtained results (Holloway et al. 2008). Secondly, testing athletes using team sport simulations allows the measurement of physiological and performance responses using specialised equipment within controlled settings. Due to the lack of control in player activity, as well as rules and regulations that are often enforced upon research procedures, some responses are not able to be readily measured during team sport matches. Therefore, simulation tests often provide information that is unobtainable during actual competition. Finally, the development of team sport simulations allows more accurate assessments of interventions such as nutritional strategies and conditioning plans. The variability in the movement patterns and intensities between matches within team sports makes it difficult to determine the precise performance effects of interventions (Nicholas et al. 2000). As such, team sport simulations impose controlled activity requirements upon athletes and thus allow intervention effects to be accurately measured.

Despite the reported advantages of team sport simulations, some limitations have also been suggested. Firstly, when developing simulation tests many studies have used non-specific exercise protocols. Such methodologies have not included core movement patterns (Abt, Reaburn, Holmes & Gear, 2003; Drust, Reilly & Cable, 1999; Preen et al. 2001; Sirotic & Coutts, 2008; Thatcher & Batterham, 2004; Wilson, Snydmiller, Game, Quinney & Bell, 2010), or specific movements (Drust et al. 2000; Fallowfield, Jackson, Wilkinson & Harrison, 1997; Nicholas et al. 2000) commonly performed within the investigated sport. Some researchers have measured performance for running-based team sports using cycle ergometers (Preen et al. 2001; Wilson et al. 2010). As such, the movement patterns specific to the team sport are unlikely to be replicated given the reported differences in muscle recruitment and contraction patterns between running and cycling activity (Green & Patla, 1992; Sloniger, Cureton, Prior & Evans, 1997). Other researchers have employed the use of non-motorised treadmill-based simulation tests, which only include straight line running (Abt et al. 2003; Drust et al. 1999; Sirotic & Coutts, 2008; Thatcher & Batterham, 2004). Subsequently, the increased metabolic costs associated with frequent directional changes and sideways or
backwards running commonly performed during team sport competition are not imposed upon the athletes during these simulation tests (Dellal et al. 2010; Reilly & Bowen, 1984). Furthermore, some protocols have not included sport-specific movements, such as jumping, static exertion, and skill-based activities (Drust et al. 2000; Edwards, Macfadyen & Clark, 2003b; Mujika et al. 2006; Nicholas et al. 2000). Such movements have frequently been suggested to elicit elevated metabolic demands on players during competition within various team sports (Deutsch et al. 2007; McInnes et al. 1995; Platanou & Geladas, 2006).

Secondly, some studies have included prolonged periods of sub-maximal activity with little changes in movement intensity (Drust et al. 2000; Fallowfield et al. 1997). It has been suggested that there are difficulties in replicating the eccentric components of muscle activity involved in rapid acceleration and deceleration commonly encountered during team sports (Spencer et al. 2004). The contribution of eccentric muscle action to overall energy expenditure is an essential component to consider when developing team sport simulations.

Thirdly, protocols have been developed using testing periods lasting less than match-specific playing durations (Bangsbo & Lindquist, 1992; Buchheit, 2008; Mujika et al. 2006; Nicholas et al. 2000). While these methodologies allow time-efficient performance assessment, it can be argued that such protocols do not sufficiently replicate the entire activity demands experienced by athletes during competition. In addition, some researchers have only included HIA or sprint data when developing team sport protocols (Buchheit, 2008; Buchheit et al. 2010; Oliver et al. 2007; Sheppard et al. 2007; Spencer et al. 2006; Tan et al. 2010; Wragg et al. 2000). Consequently, the moderate-intensity demands as well as recovery periods evident across team sport competition are likely to be omitted. These periods of play have been documented to contribute greatest to the overall match activity demands within numerous team sports (Barbero-Alvarez et al. 2008; Ben Abdelkrim et al. 2010a; Burgess et al. 2006; McInnes et al. 1995; Spencer et al. 2004). Furthermore, the recovery periods during these shortened high-intensity tests are likely to be non-specific to those experienced during competition, and thus test fatigue responses are unlikely to be indicative of those encountered during matches. Previously, declines in HIA and sprint
activity have been identified as important performance indicators during intermittent team sports such as soccer (Oliver et al. 2007) and rugby union (Roberts et al. 2010), and as such have been used as criterion measures within many team sport simulations (Bishop et al. 2001; Edwards et al. 2003b; Roberts et al. 2010; Williams et al. 2010). Therefore, to measure player performance that is specific to team sport competition, it is important to develop simulation tests representative of actual match durations.

While it is evident that many benefits do exist with the development of team sport simulation tests over other tests, the reported limitations must also be considered and where possible addressed when constructing simulations. Additionally, there are other factors requiring consideration during the development of team sport simulations, including test familiarisation, reliability, and validity.

2.6.1 Familiarisation of Team Sport Simulation Tests

Previously, researchers have suggested that participants must undergo familiarisation procedures to reduce the learning effects associated with performance of an untried team sport simulation test (Glaister et al. 2009; Wragg et al. 2000). Familiarisation typically involves verbal explanation of the test protocol, as well as performance of test trials. Within existing research, a varied quantity of familiarisation trials have been reported for team sport simulation tests (Buchheit et al. 2010; Glaister et al. 2009; Holloway et al. 2008; Mujika et al. 2006; Nicholas et al. 2000; Oliver et al. 2007; Sirotic & Coutts, 2007; Spencer et al. 2006; Williams et al. 2010; Wragg et al. 2000).

Previously, explanatory procedures have been reported to be essential during familiarisation for team sport simulations (Holloway et al. 2008; Williams et al. 2010). Additionally, participants completing simulation tests have typically been required to complete at least one test trial during familiarisation (Buchheit et al. 2010; Mujika et al. 2006; Oliver et al. 2007; Sirotic & Coutts, 2007). However, time constraints often limit the performance of full familiarisation trials for lengthy tests. Therefore, some researchers have included segments of the simulation during the familiarisation process (Nicholas et al. 2000; Williams et al. 2010). Previously, during an 85-min field-based soccer simulation test,
Nicholas et al. (2000) reported using only one 30-min trial of the test to familiarise participants. Furthermore, Williams and colleagues (2010) reported using two reduced-duration familiarisation trials for a 90-min soccer-specific simulation test on separate days. During the first trial, participants were required to run through the protocol at varied speeds until they felt confident in their performance. During the second trial they completed a 30-min segment of the test at full intensity. The use of shortened trials or single full trials during familiarisation introduces difficulties in assessing and limiting participant learning effects within team sport simulation studies (Glaister et al. 2009; Sirotic & Coutts, 2007).

To assess the learning effects in athletes during simulation familiarisation, some researchers have included multiple full test trials (Glaister et al. 2009; Spencer et al. 2006; Williams et al. 2009; Wragg et al. 2000). Previously, performance during the Ekblom Soccer-Specific Endurance Test was shown to vary between first and second performance trials, and remain consistent thereafter (Williams et al. 2009). Similar findings were reported when investigating performance during a team sport repeat-sprint test where performance was shown to vary between the first two trials, and remain relatively constant during subsequent trials (Glaister et al. 2009). It has been suggested that when measuring test performance in well-conditioned athletes, training effects are unlikely to occur given the brief stimulus of the test trial (Glaister et al. 2009). As such, within both of these above tests, one test trial was determined to be sufficient in accounting for participant learning effects. In contrast, when examining the performance of a soccer-specific simulation test across six trials, Wragg et al. (2000) reported no significant changes in performance to occur after the second trial. As such, it was concluded that two familiarisation trials of this test were required to account for learning effects.

In summary, numerous familiarisation procedures have been used when assessing performance during team sport simulation tests. The available research suggests that different familiarisation requirements exist between tests. Furthermore, varied familiarisation trials may be needed when testing different participant populations depending on their previous exposure to the activities of the test (Glaister et al. 2009). As
such, prior to commencement of the main test trials, researchers must include multiple
familiarisation trials to determine the learning effects associated with test performance
when developing team sport simulations. Additionally, multiple main trials also need to be
conducted to assess another test property, reliability.

2.6.2 Reliability of Team Sport Simulation Tests
The reliability of team sport simulation tests has largely been determined using test-retest
methodologies where multiple test performances are conducted within the same sample of
participants (Buchheit, 2008; Glaister et al. 2009; Holloway et al. 2008; Krstrup et al. 2003;
Sheppard et al. 2007; Zagatto, Beck & Gobatto, 2009). When using test-retest
methodologies, many researchers have calculated ICC (Buchheit, 2008; Glaister et al. 2009;
Sheppard et al. 2007; Tan et al. 2010; Zagatto et al. 2009) and Typical Error of Measurement
(TEM) statistics (Roberts et al. 2010; Sheppard et al. 2007; Tan et al. 2010; Wilkinson,
Leedale-Brown & Winter, 2009b; Williams et al. 2009) to determine test reliability.

The ICC indicates the strength of the relationship between test performance across multiple
trials (Hopkins, 2000a). It has been suggested that when sports performance tests are
conducted to discriminate between participants, the ICC should be calculated to determine
reliability (Impellizzeri & Marcora, 2009). Previously, it has been suggested that ICC
values >0.90 indicate high reliability, while values between 0.80-0.90 and <0.80 represent
moderate and poor levels of reliability for sports performance tests (Sassi et al. 2009).
Moreover, it has been proposed that a physical test should display an ICC of at least 0.81 to
be considered reliable for measures of sports performance (Hopkins, 2000a). However,
considering the reported limitations of ICC, including low sensitivity to changes in means
between trials and the strong influence of inter-subject variation (Wragg et al. 2000),
additional calculations are often made to provide a more comprehensive analysis of test
reliability.

The TEM has been described as the within-subject variation inherent between test scores
due mainly to biological or equipment sources (Hopkins, 2000a). The TEM has been
suggested to be the most important reliability calculation for coaches, researchers, and
other professionals using tests aimed at monitoring performance (Hopkins, 2000a). Further, the TEM can be presented in absolute or relative (%) terms. Often, as test measures increase, so does the TEM calculated between trials. Consequently, researchers often report the TEM for test measures as a percentage of their respective means, otherwise known as the CV. This allows a direct comparison of reliability between different tests irrespective of calibration or scaling used (Hopkins, 2000a). The TEM and CV have been suggested to be most practical when tests are used to evaluate changes in responses with time (Impellizzeri & Marcora, 2009). It has been proposed that measures displaying a CV <5% have high reliability, and a CV of 10% is the upper limit of acceptance for test reproducibility (Atkinson, Nevill & Edwards, 1999).

Within team sport simulation tests, a number of different measures have been utilised to evaluate athlete performance, including mean and best sprint, shuttle, and circuit times, total performance time and distance, and fatigue measures (Bishop et al. 2001; Buchheit et al. 2010; Gabbett, 2010; Glaister et al. 2009; Krüstrup et al. 2006a, 2003; Spencer et al. 2006; Williams et al. 2010; Wragg et al. 2000). Typically, adequate reliability has been observed within team sport simulations for mean (ICC = 0.95-0.97; CV = 0.9-5.9%, 95% Confidence Intervals (CI) = 0.7-10.2%) (Buchheit et al. 2010; Glaister et al. 2009; Oliver et al. 2007; Roberts et al. 2010; Williams et al. 2010; Wragg et al. 2000; Zagatto et al. 2009), best (ICC = 0.92-0.94; CV = 1.0-7.9%, 95% CI = 1.1-14.4%) (Buchheit et al. 2010; Glaister et al. 2009; Oliver et al. 2007; Zagatto et al. 2009), and total test performance measures (ICC = 0.90-0.93; CV = 1.2-9.6%, 95% CI = 0.5-6.7%) (Gabbett, 2010; Krüstrup et al. 2006a, 2003; Oliver et al. 2007; Spencer et al. 2006; Tan et al. 2010; Williams et al. 2009; Zagatto et al. 2009). However, researchers have frequently reported poor reliability in fatigue measures such as decrement in sprint performance and movement times (Buchheit et al. 2010; Gabbett, 2010; Glaister et al. 2009; Sheppard et al. 2007; Spencer et al. 2006; Tan et al. 2010). Previously, poor reliability (ICC <0.80; CV >10%) for fatigue measures has been reported in team sport simulation tests for field hockey (CV = 14.9%, 95% CI = 10.8-31.3%) (Spencer et al. 2006), soccer (CV = 19.5%) (Gabbett, 2010), explosive team sports
(CV = 22.3-34.8%; 90% CI = 15.7-61.8%) (Buchheit et al. 2010), water polo (ICC = 0.002-0.02; CV = 26.0-27.2%, 90% CI = 19.3-42.9%) (Tan et al. 2010), repeat-sprint sports (ICC = 0.59; CV = 38.7%, 95% CI = 30.9-51.7%) (Glaister et al. 2009), and volleyball (CV = 82.3%) (Sheppard et al. 2007). These findings suggest that fatigue measures within team sport simulations may be less reliable than other performance measures, and therefore should be used with discretion during performance analysis.

While the determination of ICC and TEM provides useful information concerning the reliability of a sport simulation test, a major limitation for these measures exists. Specifically, the use of generalised limits to accept ICC and TEM values as ‘good’ or ‘poor’ may not provide an accurate assessment of the inherent error involved for specific tests. It has been suggested that researchers should assess reliability relative to the analytical goals of the test (Atkinson & Nevill, 2008). Further, determining the influence of measurement error on sample size estimation for test-retest methodologies has been proposed to ascertain an acceptable level of reliability (Atkinson & Nevill, 2008). In addition, calculation of the smallest worthwhile change may provide the critical level of error needed to identify the practical usefulness of a test, and indicate that test scores are likely to be real and not simply due to testing error and typical variation (Pyne, 2003).

Therefore, when developing team sport simulation tests, researchers should determine the reliability of all test measures using multiple reliability statistics. While the reliability of team sport simulation tests provides important information on the reproducibility of test measures, an indication of test validity is also necessary.

### 2.6.3 Validity of Team Sport Simulation Tests

Validity refers to the extent to which a test actually measures what it purports to measure (Impellizzeri & Marcora, 2009). Prior to a sports performance test being implemented, the validity related to its intended functions should be determined. Previously, four major types of validity have been suggested in the development of performance tests (Impellizzeri & Marcora, 2009).
Firstly, validity can be determined based on the inherent characteristics of a test and their relationship to fitness components known to be important for the investigated sport (Wilkinson, Leedale-Brown & Winter, 2009a). Such validity is typically called content or ecological validity, and has been suggested to be important when developing team sport simulation tests (Wilkinson et al. 2009a). Previously, to assess ecological validity, researchers have compared test performance with activity measures gathered during actual team sport competition (Krstrup et al. 2003; Rampinini et al. 2007a; Souhail, Castagna, Mohamed, Younes & Chamari, 2010) and also fitness measures related to match performance (Castagna et al. 2008b; Wilkinson et al. 2009a; Williams et al. 2010).

Rampinini et al. (2007a) reported significant correlations (r = -0.60-0.65) between performance on a soccer-specific repeat-sprint simulation test and the amount of very HIA and sprinting distance performed during competition. Similarly, Krstrup et al. (2003) and Souhail et al. (2010) reported significant relationships (r = 0.71-0.88) between distance covered during the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) and total HIA (>15 km·h⁻¹) performed during soccer matches, and total distance travelled in competitive handball matches. Rampinini et al. (2007a) proposed that typical metabolic responses to repeat-sprint activity such as reduced pH, PCr, and ATP, and activation of anaerobic glycolysis may be similar to those evident during very high-intensity and sprinting movements during soccer matches. Krstrup et al. (2003) suggested that HIA performed during matches is a precise measure of soccer performance, and the intermittent characteristics of the Yo-Yo IR1 reflect the heavy requirement of frequent changes in movement intensity during soccer competition. While Souhail et al. (2010) also proposed the intermittent demands of the Yo-Yo IR1 to be similar to those experienced during handball competition. However, the high-intensity distance covered during handball matches was not a true representation of the total demands experienced by players due to the intense spot movements frequently performed.

Investigators reporting on the relationships between player fitness characteristics and simulation test performance have largely examined $\dot{V}O_{2max}$ responses in participants.
Previously, \( \text{VO}_{2\text{max}} \) has been reported to be an indicator of aerobic performance capacity in various team sport athletes, and as such has been frequently correlated with team sport simulation performance (Castagna et al. 2008b; Krustrup et al. 2006a; Krustrup et al. 2003; Wilkinson et al. 2009a; Williams et al. 2010). Within this body of research, various sport-specific simulation tests have possessed large-almost perfect relationships \((r = 0.56-0.94)\) with \( \text{VO}_{2\text{max}} \) with most reporting statistically significant correlations. As such, team sport simulation tests have typically been reported as valid in assessing the aerobic fitness of athletes. However, given the intermittent nature of most team sports, and the extensive reliance upon other fitness components throughout competition, these results are likely to have limited application to overall performance. Thus, multiple fitness measures related to actual match activity should be included when determining the ecological validity of team sport simulation tests.

Secondly, if the aim of the simulation test is to evaluate athlete performance, then the test should be validated against a criterion measure or test specific to the sport (Impellizzeri & Marcora, 2009). Criterion validity has been frequently determined for a variety of team sport simulation tests (Holloway et al. 2008; Krustrup et al. 2006a; Krustrup et al. 2003; Williams et al. 2010; Wragg et al. 2000; Zagatto et al. 2009). Previously, researchers examining the criterion validity for simulation tests have largely observed significant relationships between test performances. Krustrup et al. (2003) compared the distance travelled across the Yo-Yo IR1 to 50 m sprint performance, repeated sprint performance (5 x 30 m), and time to fatigue during an incremental treadmill test. Distance covered during the Yo-Yo IR1 was significantly related \((r = 0.79)\) to only time to fatigue during the incremental test. A similar significant relationship \((r = 0.74)\) has been documented between the Yo-Yo Intermittent Recovery level 2 Test and time to fatigue during an incremental treadmill test (Krustrup et al. 2006a). Moreover, the Yo-Yo IR1 has been used as a criterion test during validation of a soccer-specific simulation, where a significant relationship \((r = 0.76)\) was observed between the total distance covered across both tests (Williams et al. 2010). It was suggested that soccer players with a greater ability to perform repeated high-
intensity bouts would cover greater distance during the soccer-specific simulation test and presumably actual competition.

While most researchers have observed significant relationships between criterion test scores and team sport simulation measures, some have reported no such correlation to exist. For example, Wragg et al. (2000) observed a non-significant, small negative relationship \( r = -0.30 \) to exist between performances on a criterion test and a soccer-specific simulation test. It was suggested that the soccer-specific test included larger mean sprint distances than that reported for soccer competition, and as such the test demands were not match-specific. This finding highlights the need for competition specificity when developing valid team sport simulations.

Thirdly, if a test is used to select athletes, then it should be able to differentiate performance between two separate groups representing different playing levels (Impellizzeri & Marcora, 2009). This type of validity, termed construct validity, has also been frequently determined for many simulation tests in team sports such as rugby league (Serpell, Ford & Young, 2010), soccer (Gabbett, 2010), Australian Rules football (Veale, Pearce & Carlson, 2010), water polo (Mujika et al. 2006), volleyball (Sheppard et al. 2007), and generic team sport activity (Buchheit et al. 2010). Researchers have compared test measures between elite and sub-elite (Krstrup et al. 2006a; Serpell et al. 2010; Veale et al. 2010), national and state (Gabbett, 2010), playing and non-playing (Veale et al. 2010), senior and junior (Mujika et al. 2006), and male and female groups (Mujika et al. 2006) when assessing the construct validity of simulation tests. When selecting participant groups, researchers should select players from competition levels that are practically useful (Impellizzeri & Marcora, 2009). Little relevance may be provided when comparing groups with likely large sport-specific performance differences, such as playing and non-playing participants. Consequently, choosing groups from close competition levels is likely to heighten the sensitivity of the test and provide useful sport-specific data for coaches, players, and support staff. Such data may be applied during various team sport practices.
including the assessment of player conditioning programs and transitioning players to higher levels of competition.

Finally, a test that is utilised to assess performance changes over time should be correlated against changes in a criterion performance measure or test over a specified period (Impellizzeri & Marcora, 2009). Few studies have reported on this longitudinal validity for team sport simulation tests (Krstrup & Bangsbo, 2001; Mujika et al. 2006). Previously, Krstrup and Bangsbo (2001) investigated the relationship between changes in Yo-Yo IR1 performance and high-intensity running during matches in top-class soccer referees following a 12-week intermittent training intervention. A significant correlation (r = 0.77) between Yo-Yo IR1 improvements and increases in high-intensity running during matches supported the longitudinal validity of the Yo-Yo IR1. More recently, Mujika et al. (2006) examined performance changes in a water polo shuttle test over the course of a competitive season (10 months) within elite junior water polo players. It was reported that the water polo test was able to detect changes in match performance. However, this was subjectively assessed and the test was not objectively correlated against a criterion test or measure. As such, no statistical data supported these findings. The limited available literature assessing the longitudinal validity of team sport simulations suggests that methodological constraints including heavy time requirements and participant accessibility may make this assessment difficult in most testing situations. Nevertheless, when developing simulation tests that function to assess performance over time, the longitudinal validity of the test should be provided.

In summary, based on the existing evidence, team sport simulation tests should seek to include movement patterns and activity demands specific to the team sport investigated. This includes multi-directional, sport-specific, and intermittent activity requirements, as well as match-specific activity distances. Furthermore, team sport simulation tests should be determined to possess adequate reliability and validity using multiple statistical measures. Despite the increasing research detailing the development of team sport simulation tests, no match-specific basketball simulation tests exist. This in part can be attributed to the
paucity of available data describing the current activity demands of open-age male basketball competition. Consequently, researchers have largely used generic tests aimed at assessing separate elements of player fitness and performance.

2.6.4 Basketball Test Protocols

Within basketball, a variety of fitness- and performance-based tests have been developed and applied by coaches and support staff to select players for advanced level training programs. While these tests may provide useful information on player fitness capacities and performance attributes, they do not permit the complete assessment of basketball-related fitness.

2.6.4.1 Fitness-based Tests

Previously, tests utilised to assess elements of basketball fitness have been largely limited to the separate assessment of anaerobic and aerobic characteristics as discussed. Previously, relationships between scores on these tests and player success (Angyan, Teczely, Zalay & Karsai, 2003), playing time (Hoffman, Fry, Howard, Maresh & Kraemer, 1991), and team success (Groves & Gayle, 1993) have been reported in basketball players. However, such tests only present descriptive data concerning the identification of talent characteristics specific to basketball and need to be used in combination with other tests to assess both anaerobic and aerobic fitness components. As such, researchers have attempted to develop basketball-specific performance criteria and field tests to better describe and measure the performance of various cohorts of basketball players.

2.6.4.2 Performance-based Tests

To date, researchers have developed various testing procedures and protocols to identify and measure basketball-related performance within controlled settings. Such methodologies include the identification of successful basketball performance criteria, and the development of training protocols, repeat-sprint tests, and intermittent tests (Barfield et al. 2007; Carvalho et al. 2011; Castagna et al. 2008b, 2010; Grehaigne & Godbout, 1995; Hoffman et al. 2000; Trninic & Dizdar, 2000; Trninic, Perica & Dizdar, 1999). However,
various limitations exist for each of these methodologies in the assessment of basketball-related performance.

The development of definitive performance criteria for team sport athletes can be difficult as performance is influenced by many competition factors including tactical decisions, opposition ability, and refereeing decisions (Grehaigne & Godbout, 1995; Trninic & Dizdar, 2000; Trninic et al. 1999). Despite this, researchers investigating basketball performance have attempted to identify actions and skills necessary for success (Trninic & Dizdar, 2000; Trninic et al. 1999). Trninic and Dizdar (2000) developed seven criteria for assessing defensive basketball performance and 12 criteria for assessing offensive basketball performance. Based on the intra-observer agreement between 10 basketball experts, specific elements of play were identified as most important for different playing positions.

For the point guard and shooting guard positions, level of defensive pressure and transition defensive efficiency were judged to be of the highest importance on defence, while offensive play, ball control, and passing skills were most important for point guards and shooting and dribble penetration for shooting guards during offence. For small forwards, transition defence efficiency, and outside shooting and dribble penetration were ranked highest during defensive and offensive play (Trninic & Dizdar, 2000). Additionally, the spread of medium-high weighting on most defensive and offensive criteria within this position indicated the versatility required during competition. Within power forward and centre positions, defensive rebounding efficiency, and inside shooting and offensive rebounding efficiency were judged to be of very high importance during defence and offence. These requirements largely reflect the court positioning and roles of different basketball playing positions as well as the physical attributes typically accompanying these positions. While these data do not allow for the direct assessment of basketball-specific fitness, they may prove useful in explaining the observed match activity demands within basketball TMA studies.

In addition to the identification of performance criteria, basketball-specific training protocols have been developed to replicate aspects of match activity patterns (Balciunas et
Previously, Crisafulli and colleagues (2002) have suggested that there are major difficulties in reproducing basketball performance within laboratory settings, and as such many physiological characteristics of the sport have yet to be described. In an attempt to design a basketball-specific field test, Crisafulli et al. (2002) developed the following protocol: player sits on the sideline for 4 min (physiological responses measured during rest); player then performs five play sequences with possession of the ball, starting from the half-way line with a shot at the end of each sequence and then returning to the half-way line; player then returns to the sideline and remains seated for 5 min (physiological responses measured during recovery). The investigators suggested that this test can provide important physiological and biomechanical player data, especially in response to anaerobic activity. However, this protocol was not based on any match-specific activity data. Furthermore, considering the dribbling component included in the test, the applicability of this protocol across all playing positions can be argued. Therefore, the low external validity of this basketball field test indicates that the acquired data may not reflect actual match-specific player responses.

More recently, Balciunas et al. (2006) developed a high intensity basketball-specific training protocol and observed it to benefit young competitive Lithuanian male basketball players. The protocol consisted of 4 x 15-min periods of technical and tactical actions. The first period was directed towards passing actions, the second towards dribbling activity, the third towards shooting, and the final period towards tactical play. Two 2-min passive periods were used for free-throw shooting and an extended 15-min passive period was used for tactical instruction. This training protocol produced noticeable improvements in anaerobic capacity and game performance in the players across a 4-month period (Balciunas et al. 2006). Balciunas et al. (2006) suggested that these benefits were due to the targeting of both the anaerobic and aerobic demands of basketball competition, as well as the inclusion of external structural aspects of the sport, such as technical and tactical actions.

While this basketball training protocol was based on kinematic data collected during match play, it is not representative of the complete activity demands of actual competition. The
inclusion of separated periods of long durations is not typical of the frequent changes in movement type experienced during basketball matches. Furthermore, existing positional differences in activity during competition suggest that focusing entire testing sequences on specific elements of play such as dribbling may not be practical for some players (Ben Abdelkrim et al. 2007; Trninic & Dizdar, 2000). Therefore, the development of a valid and reliable basketball-specific test that simulates the precise activity demands of competition and is applicable to all playing positions may prove invaluable in the assessment and monitoring of player conditioning and performance.

In addition to these training-based tests, other researchers have reported using line drill and repeat-sprint tests to measure basketball fitness (Carvalho et al. 2011; Castagna et al. 2008b; Hoffman et al. 2000; Montgomery, Pyne, Hopkins & Minahan, 2008c). The line drill test is anaerobic in nature and involves repeated high-intensity efforts of varied distances across a basketball court (Carvalho et al. 2011). Previously, the validity of this test has been supported for the assessment of anaerobic power in basketball players evidenced by significant rank correlations with VJ performance ($\tau = 0.58-0.72$) (Hoffman et al. 2000), and significant small correlations with PP ($r = 0.39$) and MP ($r = 0.43$) across a Wingate test (Carvalho et al. 2011). Furthermore, Castagna et al. (2009) developed a basketball-specific repeat-sprint test based on the stride-sprint demands experienced by elite male basketball players during competition. However, the activity demands of both the line drill and repeat-sprint tests are not indicative of those reported for competitive basketball matches within TMA studies (Ben Abdelkrim et al. 2010a, 2007; McInnes et al. 1995). Previously, basketball TMA research has highlighted the important contributions of sport-specific activity such as jumping and shuffling to the anaerobic demands of basketball matches (Ben Abdelkrim et al. 2010a, 2007; McInnes et al. 1995). As such, field tests assessing basketball-specific anaerobic performance may need to include such movements. Furthermore, the aforementioned basketball repeat-sprint test was developed using match activity data from junior basketball players, who have been observed to experience lower sprint demands across competition than adult male players (Ben Abdelkrim et al. 2007; McInnes et al. 1995).
Thus, these high-intensity tests are not likely to replicate the complete anaerobic requirements of open-age male basketball competition.

Furthermore, Castagna et al. (2008b; 2010) suggested general and specific intermittent field tests were valid in assessing elements of basketball fitness. The Yo-Yo IR1 displayed adequate validity in assessing aerobic fitness in junior basketball players as evidenced by a significant relationship ($r = 0.77$) with ${\dot{V}O}_{2\text{max}}$. Furthermore, the Yo-Yo IR1 was also significantly related ($r = -0.52$) to post-match decrements in line drill performance, and thus was suggested to be a valid test in assessing match-related anaerobic fatigue in basketball players (Castagna et al. 2008b). In addition to the Yo-Yo IR1, Castagna et al. (2010) observed a significant relationship ($r = 0.82$) between speed reached at AnT during a basketball-specific intermittent shuttle test and incremental treadmill progressive test. It was concluded that this test was valid in assessing sub-maximal aerobic fitness in basketball players.

Despite their validity in assessing elements of basketball fitness, the Yo-Yo IR1 and basketball intermittent test may hold a number of limitations in assessing match-related fitness within open-age male basketball players. Firstly, these tests were validated in junior basketball populations, who have been observed to experience lower match demands than open-age players (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Secondly, both tests employed shuttle-based protocols without including basketball-specific activity, such as shuffling and jumping. Such movements have been suggested to heighten the metabolic stress placed on players during basketball activity (McInnes et al. 1995). Finally, the basketball intermittent test was validated against line drill decrements following practice matches lasting shorter durations than actual competition. Previously, practice activity has been observed to impose lower physiological loads upon players than actual competition (Montgomery et al. 2010). Thus the observed fatigue responses within these tests may not correspond to those experienced across competitive basketball matches (Barbero-Alvarez et al. 2008; Montgomery et al. 2010).
There are many limitations within existing research using fitness parameters and performance tests to assess basketball performance. Furthermore, the reliability, as well as the ecological, criterion, construct, and longitudinal validity have not been described in combination for any of these tests. As a result, no reliable and valid basketball-specific test representative of actual open-age competition activity demands currently exists.

2.6.5 The Development of a Basketball Simulation Test

The activity requirements of basketball have been characterised as highly intermittent, with extensive involvement of both the glycolytic and oxidative energy systems (Ben Abdelkrim et al. 2007; Bishop & Wright, 2006; McInnes et al. 1995). These demands have been previously quantified using various methodologies. However, the precise activity demands experienced during open-age male basketball competition remain unknown.

Given the limited available data detailing the activity requirements of open-age male basketball competition, no basketball simulation tests exist. Several test protocols have been developed to simulate match activity demands in other team sports, such as rugby league (Holloway et al. 2008), soccer (Nicholas et al. 2000; Oliver et al. 2007; Williams et al. 20010; Wragg et al. 2000), rugby union, (Roberts et al. 2010), and netball (Higgins et al. 2009). However, the demands imposed during these tests are likely to differ from the requirements of basketball competition due to the varied playing areas, skill sets, and rules and regulations within these sports. Therefore, the development of a basketball simulation test is warranted and may prove useful in conditioning assessment, player selection, talent identification, and intervention testing (Roberts et al. 2010). However, before the development of such a test, some major factors should be considered.

In order to develop a basketball simulation test, researchers must have access to precise data that describe the activity demands placed upon players during actual competition. Whilst the current match activity demands imposed on open-age male basketball players remain undescribed, the present thesis will provide this information. With these data, a basketball simulation test that closely replicates the activity demands of current elite open-age male basketball competition can be developed. It is also important to recognise that the
inclusion of specific skills such as ball dribbling may be impractical when developing such testing protocols. However, other basketball-specific activities such as jumping and shuffling can be included in simulation tests. Therefore, a basketball simulation test should contain match-specific quantities of practical activities performed during match play if it is to replicate actual competition demands.

The reliability and validity data concerning the performance of a developed basketball simulation test should also be provided. Multiple statistical analyses should be performed to assess the reliability, as well as the ecological, criterion, construct, and longitudinal validity of a basketball simulation test. This provides valuable information concerning the reproducibility of the test, as well as its ability to assess, differentiate, and evaluate basketball-related fitness within and between players.

2.7 CONCLUSION

The present review of the research literature has described the available data detailing the anthropometric and fitness characteristics as well as the physiological and activity match responses of male basketball players. Furthermore, existing research directly comparing these measures between levels of basketball competition has also been discussed. Finally, the incorporation of such data, as well as the methodological issues encountered, during the development of team sport simulation tests was addressed.

In summary, existing literature has largely described the physiological responses of male basketball players across matches, with less research reporting on competition activity demands. Furthermore, the available basketball competition activity data is not reflective of the current demands experienced by Australian or open-age male basketball players, as previous studies have examined match activity requirements under superseded match rules (McInnes et al. 1995), across age-restricted (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006) or preseason/practice competition (McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006), within female athletes (Matthew & Delextrat, 2009; Narazaki et al. 2009), or using non-specific movement categories (Bishop & Wright, 2006; Erculj et al.
2008; Narazaki et al. 2009; Tessitore et al. 2006). Thus, provision of current match activity data is necessary for the development of a valid team sport simulation test. Such tests allow the measurement of player responses not attainable during actual competition as well as the precise assessment of interventions (Drust et al. 2000; Higgins et al. 2009; Preen et al. 2001). However, no such tests have been developed that are specific to open-age male basketball competition.

The present research thesis aims to address these identified deficiencies within the existing literature through the description and comparison of the current activity demands of elite and sub-elite open-age Australian male basketball competitions, and subsequent development of the first known basketball simulation test.
Chapter 3

A comparison between the activity demands of elite and sub-elite open-age Australian male basketball competitions

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3.0 ABSTRACT

The purpose of this study was to describe and compare the activity demands of current elite and sub-elite open-age Australian male basketball competitions. Elite (n = 10; age: 28.3 ± 4.9 yr; stature: 197.4 ± 8.3 cm; body mass: 97.0 ± 13.9 kg) and sub-elite (n = 12; 26.1 ± 5.3 yr; 191.4 ± 7.6 cm; 85.9 ± 13.2 kg) Australian basketball players volunteered to participate. Player activity was analysed using video-based time-motion analysis (TMA) across multiple (elite: n = 2; sub-elite: n = 3) in-season competition matches. Customised analytical software was used to calculate player activity into frequencies, mean and total durations (s), and mean and total distances (m) for standing/walking, jogging, running, sprinting, low shuffling, high shuffling, and dribbling movements. Movement frequency was also calculated for jumping and upper-body activity. Elite players performed significantly more total movement changes (2743 ± 133 vs. 1972 ± 175, \( p < 0.05 \)), and experienced greater activity workloads at jogging (2184 ± 34 m vs. 1786 ± 70 m, \( p < 0.01 \)) and running intensities (2989 ± 42 m vs. 2040 ± 81 m, \( p < 0.001 \)) than sub-elite players. However, sub-elite players performed significantly (\( p < 0.01 \)) more standing/walking (765 ± 18 s vs. 1080 ± 65 s) and sprinting activity (11 ± 2 s vs. 120 ± 20 s). These data suggest that elite basketball competition requires players to work more consistently at or above moderate intensities and execute a greater intermittent workload than sub-elite competition. In contrast, sub-elite competition appears to involve greater bursts of maximal activity, and longer recovery periods.

Key words: team sports; time-motion analysis; activity profile.
3.1 INTRODUCTION

Video-based time-motion analysis (TMA) technologies have been widely used to assess the activity demands of athletes during team sport competition (Barbero-Alvarez et al. 2008; Dawson et al. 2004; Deutsch et al. 2007; Lupo et al. 2010; Mohr et al. 2008; Sirotic et al. 2009). The resultant data provide information about the movement patterns experienced by team sport athletes across matches (Dobson & Keogh, 2007). Within basketball, the majority of research describing competitive match demands has investigated the physiological responses of male players during match play (Ben Abdelkrim et al. 2010a, 2010b, 2009, 2007; Janeira & Maia, 1998; McLnnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Tessitore et al. 2006; Vaquera Jimenez et al. 2008). Less research attention has been given to applying video-based TMA methodology to examine the demands experienced by male players during basketball competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Erculj et al. 2008; Janeira & Maia, 1998; McLnnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006).

Previous research examining the physiological responses of male basketball players during basketball matches has largely examined heart rate (HR) and blood lactate (BLa) responses (Ben Abdelkrim et al. 2010a, 2010b, 2007; Janeira & Maia, 1998; McLnnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008). Elite male basketball competitions have been reported to elicit mean HR responses between 151-171 b·min⁻¹ or 80-94 %HRmax (Ben Abdelkrim et al. 2010a, 2010b, 2007; McLnnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008) and mean blood lactate concentrations ([BLa]) of 3.7-6.8 mmol·L⁻¹ (Ben Abdelkrim et al. 2009, 2007; McLnnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). However, these measures only provide an indirect assessment of the demands experienced during basketball competition (Bangsbo et al. 1991; Rodriguez-Alonso et al. 2003). The use of video-based TMA provides a more direct analysis of the activity requirements of basketball competition.
Existing research examining player activity during male basketball competition has reported elite players to perform mean total movement frequencies between 997-1105 (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995). Additionally, previous TMA research has described the activity demands of male basketball competition through the proportions of playing time spent moving at different movement intensities. Disparities in time spent performing low- (LIA) (50-72%), moderate- (MIA) (17-43%), and high-intensity activity (HIA) (6-20%) have been previously reported (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; McInnes et al. 1995). Taken together, the available physiological and TMA evidence suggests that basketball is highly intermittent in nature.

There is wide variation in the findings of existing studies examining the match activity demands of basketball, most likely due to the different methodologies used. Previously, researchers have investigated basketball match activity demands under superseded rules (Janeira & Maia, 1998; McInnes et al. 1995), across age-restricted and pre-season/practice competitions (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006), within female competitions (Matthew & Delextrat, 2009), or using broad movement categories (Bishop & Wright, 2006; Narazaki et al. 2009; Tessitore et al. 2006). Therefore, the activity demands of current open-age male basketball competition remain largely unknown.

Furthermore, the examination of playing level differences in match demands provides important data for the development of specific training plans and transitioning of players to higher competitions (Sirotic et al. 2009). To date, only one study has directly compared match activity demands across different playing standards (Ben Abdelkrim et al. 2010a). However, these data are representative of junior basketball matches, which may differ to open-age male competition considering the reported differences in physical and performance characteristics between these playing groups (Ben Abdelkrim et al. 2010c). Furthermore, only movement frequencies and proportion of live time spent performing each activity were provided within this research (Ben Abdelkrim et al. 2010c). Thus, there is a need for more detailed activity data such as distance and mean bout measurements to
provide greater insight into match demand differences between playing levels, especially in open-age male basketball competitions.

Therefore, the aims of this study are to firstly describe the activity demands of current open-age Australian male basketball competition and secondly, to compare these demands between elite and sub-elite playing levels.

3.2 METHODS

3.2.1 Participants

Elite male players from the Australian National Basketball League (NBL) (n = 10; age: 28.3 ± 4.9 yr; stature: 197.4 ± 8.3 cm; body mass: 97.0 ± 13.9 kg) and sub-elite male players from the Queensland Basketball League (QBL) (n = 12; 26.1 ± 5.3 yr; 191.4 ± 7.6 cm; 85.9 ± 13.2 kg) volunteered to participate in this research. Within Australia, the NBL is the highest standard of competition, while the QBL forms part of a second-tier state competition that is conducted nation-wide. All players had completed pre-season conditioning programs consisting of a combined training plan of agility, plyometric, anaerobic, and endurance components prior to the start of the playing season. For the duration of data collection, all players were training for ~6 h and participating in a maximum of two competitive matches per week. Only one match was played per week when video data were collected. All research methodologies and procedures were approved by the CQUniversity Human Research Ethics Committee.

3.2.2 Video Analysis

A between-subjects research design was utilised within this study. Elite player activity was collected across two competitive matches around the mid- and end-season. Sub-elite player activity was collected across three matches throughout the competitive season. All five matches consisted of 4 x 12-min quarters, with 3-min breaks between the first and second and third and fourth quarters, and a 10-min half-time break.

All video data for the elite players were collected using a JVC Everio GZ-HD10 colour camcorder (Hagemeyer, Kingsgrove, Australia) with a JVC GL-AT30 telephoto conversion
lens (Hagemeyer, Kingsgrove, Australia) mounted in a fixed position aligned with the half-way point on an indoor basketball court at a height (~20 m) and distance (~12 m) from the sideline for all player activity to be recorded in one view. Recordings of elite matches were taken at a sample rate of 25 Hz. Due to spatial restrictions, video data for the sub-elite players were collected using two wide-angle Basler A602FC colour cameras (Basler Vision Technologies, Ahrensburg, Germany) mounted in fixed positions. Each camera was positioned as close as possible to the half-way line at a height (~6 m) and distance (~2 m) to capture all activity within one half of the court. Camera recordings for sub-elite matches were synchronised across video acquisition and overlapped at the half-way line. All sub-elite recordings were taken at a sample rate of 7.5 Hz to allow for adequate storage of the collected video data onto a computer. All video analyses were performed using a frame-by-frame manual tracking system within customised Labview software (National Instruments, Texas, USA).

Prior to match analysis, the frame rate of each video file was normalised to allow for more accurate comparisons between elite and sub-elite video data. Elite video data was analysed during every third frame to match the sampling frequency of the sub-elite video data. Each camera view was calibrated using a four-point transformation with pre-measured distance dimensions of the playing area. The calibration procedure allowed reference distances on the video view to be developed, and distances travelled to be calculated during subsequent player tracking. This allowed reconstruction of the collected images to account for perspective (parallax) errors associated with the different camera views. Movement velocity (m·s⁻¹) was calculated using the determined distance data and the time between player tracking points for the normalised frame rate.

### 3.2.3 Time-Motion Analysis

Player activity measures were calculated for players overall, and according to backcourt (BC) (guards) and frontcourt positions (FC) (forwards and centres). This simplified the identification of playing positions during the tracking process by eliminating the difficulties associated with following players who move between the five on-court positions (point
guard, shooting guard, small forward, power forward, and centre) during matches. Further, such data breakdown allowed position-specific comparisons between playing levels to be conducted. Data from substituted players were cumulated overall and within each position across matches.

Players were filmed for entire matches including all stoppages in play. Activity demands were analysed only during live match time, which included all movements when the game clock was running, as well as active phases of the match when the game clock was still, such as in-bounds passing and free-throw positioning. All analyses were performed by a single member of the research team.

The following movement categories and velocities were developed within the current study:

1. **Standing/walking**: multi-directional movement performed at a velocity of 0-1.0 m·s⁻¹, when not in a defensive stance.
2. **Jogging**: multi-directional movement performed at a velocity of 1.1-3.0 m·s⁻¹, when not in a defensive stance.
3. **Running**: multi-directional movement performed at a velocity of 3.1-7.0 m·s⁻¹, when not in a defensive stance.
4. **Sprinting**: multi-directional movement performed at a velocity of >7.0 m·s⁻¹, when not in a defensive stance.
5. **Low shuffling**: any multi-directional movement performed strictly in a defensive stance position at a velocity of ≤2.0 m·s⁻¹.
6. **High shuffling**: any multi-directional movement performed strictly in a defensive stance position at a velocity of >2.0 m·s⁻¹.
7. **Dribbling**: any movement in which a player is actively in possession of and dribbling the ball in any direction.
8. **Jumping**: any movement or activity whereby a player initiates a jumping action and breaks feet contact with the playing surface. This activity was recorded as a discrete movement with no duration or distance data calculated.
9. Upper-body movements: any upper-body action that involves the raising of one or both arms above the horizontal. These movements were analysed both independently of and simultaneously with other movements, apart from shuffling and dribbling activity. This activity was recorded as a discrete movement.

The categorisation of activity type was based on previously-determined velocities for court-based team sport activity (Barbero-Alvarez et al. 2008). Furthermore, all activity categories were calculated using multi-directional analysis, including backward and forward motion as well as lateral motion when not deemed to be in a defensive stance position. The determination of discrete and shuffling movements was based on the subjective interpretation of the researchers (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Mean frequency, mean bout and total duration spent (s), and mean bout and total distance travelled (m) were calculated across entire matches for each movement category. Further, duration and distance data were categorised as LIA (standing/walking and low shuffling), MIA (jogging and running), and HIA (sprinting and high shuffling).

3.2.4 Intra- and Inter-tester Reliability

To assess the intra-tester reliability of the video-based TMA methods employed in this study, one quarter of play from both elite and sub-elite recordings were randomly analysed on three occasions by the same researcher. Each analysis was separated by a minimum of 4 weeks to minimise the magnitude of data retention on the selected video footage (Duthie et al. 2003). To assess the inter-tester reliability of the TMA methodology, one quarter of play from both elite and sub-elite recordings were randomly analysed by two separate researchers (McInnes et al. 1995). Reliability was determined using Intra-class Correlation Coefficient (ICC), Typical Error of Measurement (TEM), and Coefficient of Variation (CV) (%) calculations as previously used in TMA studies (Deutsch et al. 2007; McInnes et al. 1995). All intra- and inter-tester reliability analyses were performed using the spreadsheet methods of Hopkins (2000b) and Microsoft Excel™ (Microsoft, Redmond, Washington, USA).

The intra- and inter-tester reliability of the TMA methodology were deemed acceptable (see Appendix 4) based on previous recommendations for sport simulation tests (Duthie et al. 2003).
Most measures displayed good (CV <5%) to moderate (CV = 5-10%) reliability. However, elite sprint frequency (14.0%) and mean distance (12.4%) exhibited poor intra-tester reliability (CV >10%). Furthermore, elite high shuffle mean duration (15.2%) and sprint mean distance (12.4%), and sub-elite low shuffle frequency (26.5%), total duration (13.9%) and distance (13.6%), dribbling frequency (16.5%) and total distance (16.0%), and sprint mean distance (12.8%) displayed poor inter-tester reliability (Duthie et al. 2003). Despite the poor reliability within sprinting and shuffling movements, the calculated error is still less than previously reported for HIA using GPS technologies (Coutts & Duffield, 2010a).

In addition to CV, the ICC values (0.84-1.00) calculated for each measure support the intra-tester reliability of the present methods (Hopkins, 2000a). All measures possessed acceptable inter-tester ICC (0.82-1.00), except elite mean stand/walk distance (0.63) and duration (0.77), and sub-elite mean run (0.69) and stand/walk (0.76) duration, mean sprint distance (0.65), and sprint (0.62) and low shuffle frequency (0.71). Only one researcher performed the present analysis, therefore the intra-tester reliability measures should be considered when interpreting the reported data.

### 3.2.5 Statistical Analyses

Means (± SD) were determined for all descriptive and activity measures. Prior to using parametric statistical analyses, Shapiro-Wilks Test and Levene’s Test for equality supported the normality and homogeneity of variance of the present data. Statistically significant differences between competition levels were identified using Student’s unpaired t-tests. Cohen’s $d$ was also calculated to determine the effect size (ES) between groups and was interpreted using the following criteria: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and >2.0, very large (Hopkins, 2002). All statistical analyses were performed using the spreadsheet methods of Hopkins (2000b), Microsoft Excel™ (Microsoft, Redmond, Washington, USA), and Statistical Package for Social Sciences (SPSS) software (Version 17.0, SPSS Inc., Chicago, Illinois, USA). Statistical significance was accepted at $p < 0.05$. 
3.3 RESULTS

The mean (± SD) overall and positional results for total match activity frequencies within each movement category for elite and sub-elite players are presented in Table 3.1. Significant activity frequency differences were evident between competition levels for all, BC, and FC players within standing/walking ($p = 0.005-0.008$, ES = 4.4-6.8), jogging ($p = 0.008-0.011$, ES = 5.4-6.1), sprinting ($p = 0.004-0.007$, ES = 3.9-11.7), low shuffling ($p = 0.005-0.035$, ES = 3.2-7.0), and upper-body activity ($p \leq 0.001-0.034$, ES = 4.9-5.7), and total movements ($p = 0.014-0.024$, ES = 3.7-5.5). In addition, significant activity frequency differences existed for all players during running ($p = 0.019$, ES = 4.5) and high shuffling ($p = 0.027$, ES = 3.8), and for BC players during running ($p = 0.004$, ES = 3.1).

The overall and positional results for mean and total durations (mean ± SD) spent performing within each movement category during elite and sub-elite competitions are presented in Table 3.2. Significant mean bout duration differences were apparent between competition levels for all, BC, and FC players for standing/walking ($p < 0.001$, ES = 12.1-14.8), and sprinting ($p < 0.001$, ES = 18.4-28.5). Furthermore, significant mean bout duration differences were evident between competition levels for all players during jogging ($p = 0.031$, ES = 3.8), and high shuffling ($p = 0.032$, ES = 3.7), and for FC players during jogging ($p = 0.009$, ES = 5.3), and low shuffling ($p < 0.001$, ES = 25.1).

Significant differences between competition levels also existed in the total duration data for all, BC, and FC players for standing/walking ($p = 0.008-0.023$, ES = 4.6-6.6), jogging ($p = 0.006-0.01$, ES = 3.7-6.0), running ($p \leq 0.001-0.005$, ES = 5.5-32.6), and sprinting ($p = 0.006-0.034$, ES = 4.3-11.5). Further significant competition level differences were evident in all players for low shuffling ($p = 0.042$, ES = 2.9), and dribbling ($p = 0.04$, ES = 3.0), and in BC players ($p = 0.012$, ES = 2.7) for dribbling.
Table 3.1: The overall and positional mean (± SD) match frequencies of various movements performed by elite (n = 2) and sub-elite (n = 3) open-age Australian male basketball players.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Stand/walk</th>
<th>Jog</th>
<th>Run</th>
<th>Sprint</th>
<th>Low shuffle</th>
<th>High shuffle</th>
<th>Dribble</th>
<th>Jump</th>
<th>Upper-body</th>
<th>All movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite (All)</td>
<td>794 ± 61*</td>
<td>937 ± 46*</td>
<td>509 ± 31*</td>
<td>22 ± 3*</td>
<td>65 ± 5*</td>
<td>63 ± 7*</td>
<td>41 ± 2</td>
<td>50 ± 4</td>
<td>263 ± 8*</td>
<td>2743 ± 133*</td>
</tr>
<tr>
<td>EBC</td>
<td>764 ± 86#</td>
<td>911 ± 6#</td>
<td>504 ± 38#</td>
<td>18 ± 7#</td>
<td>75 ± 5#</td>
<td>70 ± 5</td>
<td>60 ± 4</td>
<td>42 ± 6</td>
<td>289 ± 15#</td>
<td>2733 ± 142#</td>
</tr>
<tr>
<td>EFC</td>
<td>815 ± 45\†</td>
<td>955 ± 33\†</td>
<td>513 ± 26</td>
<td>24 ± 1\†</td>
<td>58 ± 12\†</td>
<td>59 ± 14</td>
<td>23 ± 1</td>
<td>56 ± 2</td>
<td>246 ± 3\†</td>
<td>2749 ± 137\†</td>
</tr>
<tr>
<td>Sub-elite (All)</td>
<td>504 ± 42</td>
<td>632 ± 65</td>
<td>339 ± 44</td>
<td>125 ± 21</td>
<td>36 ± 3</td>
<td>28 ± 11</td>
<td>41 ± 1</td>
<td>46 ± 1</td>
<td>220 ± 7</td>
<td>1972 ± 175</td>
</tr>
<tr>
<td>SEBC</td>
<td>462 ± 47</td>
<td>586 ± 77</td>
<td>321 ± 75</td>
<td>105 ± 31</td>
<td>45 ± 9</td>
<td>46 ± 29</td>
<td>72 ± 3</td>
<td>41 ± 3</td>
<td>233 ± 6</td>
<td>1911 ± 283</td>
</tr>
<tr>
<td>SEFC</td>
<td>532 ± 38</td>
<td>664 ± 59</td>
<td>352 ± 25</td>
<td>140 ± 14</td>
<td>30 ± 3</td>
<td>17 ± 3</td>
<td>19 ± 2</td>
<td>49 ± 3</td>
<td>211 ± 9</td>
<td>2014 ± 131</td>
</tr>
</tbody>
</table>

EBC = Elite backcourt; EFC = Elite frontcourt; SEBC = Sub-elite backcourt; SEFC = Sub-elite frontcourt.

* Significant (p < 0.05) difference between elite and sub-elite players;

\# Significant (p < 0.05) difference between EBC and SEBC players;

\† Significant (p < 0.05) difference between EFC and SEFC players.
Table 3.2: The overall and positional mean bout and total durations (s) (mean ± SD) spent performing various movements by elite (n = 2) and sub-elite (n = 3) open-age Australian male basketball players during match play.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Elite (All) Mean Duration (s)</th>
<th>EBC Mean Duration (s)</th>
<th>EFC Mean Duration (s)</th>
<th>Sub-elite (All) Mean Duration (s)</th>
<th>SEBC Mean Duration (s)</th>
<th>SEFC Mean Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand/walk</td>
<td>0.97 ± 0.10*</td>
<td>0.91 ± 0.09#</td>
<td>1.02 ± 0.10†</td>
<td>2.14 ± 0.05</td>
<td>2.13 ± 0.11</td>
<td>2.16 ± 0.07</td>
</tr>
<tr>
<td>Jog</td>
<td>1.26 ± 0.05*</td>
<td>1.27 ± 0.07</td>
<td>1.25 ± 0.05†</td>
<td>1.61 ± 0.12</td>
<td>1.66 ± 0.18</td>
<td>1.57 ± 0.07</td>
</tr>
<tr>
<td>Run</td>
<td>1.38 ± 0.09</td>
<td>1.34 ± 0.10</td>
<td>1.43 ± 0.09</td>
<td>1.36 ± 0.14</td>
<td>1.38 ± 0.16</td>
<td>1.33 ± 0.03</td>
</tr>
<tr>
<td>Sprint</td>
<td>0.51 ± 0.01*</td>
<td>0.51 ± 0.01</td>
<td>0.51 ± 0.03†</td>
<td>0.96 ± 0.02</td>
<td>0.93 ± 0.03</td>
<td>0.98 ± 0.02</td>
</tr>
<tr>
<td>Low shuffle</td>
<td>1.38 ± 0.04</td>
<td>1.42 ± 0.07</td>
<td>1.34 ± 0.02†</td>
<td>1.86 ± 0.29</td>
<td>1.80 ± 0.45</td>
<td>1.98 ± 0.03</td>
</tr>
<tr>
<td>High shuffle</td>
<td>0.70 ± 0.05*</td>
<td>0.77 ± 0.08</td>
<td>0.62 ± 0.06</td>
<td>0.97 ± 0.09</td>
<td>0.99 ± 0.16</td>
<td>0.84 ± 0.09</td>
</tr>
<tr>
<td>Dribble</td>
<td>3.36 ± 0.28</td>
<td>3.95 ± 0.36</td>
<td>1.62 ± 0.11</td>
<td>3.75 ± 0.24</td>
<td>4.28 ± 0.32</td>
<td>1.87 ± 0.33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Movement</th>
<th>Elite (All) Total Duration (s)</th>
<th>EBC Total Duration (s)</th>
<th>EFC Total Duration (s)</th>
<th>Sub-elite (All) Total Duration (s)</th>
<th>SEBC Total Duration (s)</th>
<th>SEFC Total Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand/walk</td>
<td>765 ± 18*</td>
<td>691 ± 35*</td>
<td>829 ± 8†</td>
<td>1080 ± 65</td>
<td>981 ± 81</td>
<td>1150 ± 68</td>
</tr>
<tr>
<td>Jog</td>
<td>1177 ± 11*</td>
<td>1153 ± 6*</td>
<td>1192 ± 24†</td>
<td>1013 ± 37</td>
<td>961 ± 45</td>
<td>1039 ± 53</td>
</tr>
<tr>
<td>Run</td>
<td>703 ± 5*</td>
<td>673 ± 9†</td>
<td>730 ± 3†</td>
<td>456 ± 20</td>
<td>436 ± 60</td>
<td>467 ± 11</td>
</tr>
<tr>
<td>Sprint</td>
<td>11 ± 2*</td>
<td>9 ± 1*</td>
<td>12 ± 3†</td>
<td>120 ± 20</td>
<td>97 ± 29</td>
<td>136 ± 15</td>
</tr>
<tr>
<td>Low shuffle</td>
<td>90 ± 10*</td>
<td>105 ± 17</td>
<td>79 ± 1</td>
<td>66 ± 6</td>
<td>78 ± 5</td>
<td>61 ± 6</td>
</tr>
<tr>
<td>High shuffle</td>
<td>44 ± 8*</td>
<td>53 ± 12</td>
<td>36 ± 1</td>
<td>27 ± 12</td>
<td>48 ± 32</td>
<td>13 ± 3</td>
</tr>
<tr>
<td>Dribble</td>
<td>138 ± 5*</td>
<td>266 ± 8†</td>
<td>37 ± 2</td>
<td>153 ± 5</td>
<td>309 ± 21</td>
<td>37 ± 10</td>
</tr>
</tbody>
</table>

EBC = Elite backcourt; EFC = Elite frontcourt; SEBC = Sub-elite backcourt; SEFC = Sub-elite frontcourt.

* Significant (p < 0.05) difference between elite and sub-elite players;

† Significant (p < 0.05) difference between EBC and SEBC players;

‡ Significant (p < 0.05) difference between EFC and SEFC players.
The overall and positional results for mean and total match distances (mean ± SD) covered performing within each movement category for elite and sub-elite players are presented in Table 3.3. Significant differences in mean bout distances between playing levels for all, BC, and FC players were observed for standing/walking ($p \leq 0.001-0.002$, ES = 9.2-12.2), and sprinting ($p \leq 0.001-0.002$, ES = 10.3-19.5). Significant competition levels differences in mean bout distance were also evident in FC players during jogging ($p = 0.028$, ES = 4.1), and in all ($p = 0.02$, ES = 10.6) and BC players ($p = 0.041$, ES = 10.6) during dribbling.

Furthermore, significant differences between playing levels for all, BC, and FC players were apparent for total distance travelled standing/walking ($p = 0.008-0.014$, ES = 4.2-6.6), jogging ($p = 0.006-0.041$, ES = 5.3-7.2), running ($p \leq 0.001-0.002$, ES = 4.8-15.5), and sprinting ($p = 0.002-0.013$, ES = 3.9-7.4). Significant competition level differences existed in all ($p = 0.009$, ES = 5.7) and BC players ($p = 0.023$, ES = 4.3) for dribbling.
Table 3.3: The overall and positional mean bout and total distances (m) (mean ± SD) travelled for various movements by elite (n = 2) and sub-elite (n = 3) open-age Australian male basketball players during match play.

<table>
<thead>
<tr>
<th></th>
<th>Stand/walk</th>
<th>Jog</th>
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<th>High shuffle</th>
<th>Dribble</th>
<th>All movements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Distance (m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite (All)</td>
<td>0.51 ± 0.06*</td>
<td>2.33 ± 0.08</td>
<td>5.89 ± 0.44</td>
<td>3.88 ± 0.16*</td>
<td>1.27 ± 0.08</td>
<td>2.08 ± 0.15</td>
<td>9.89 ± 0.08*</td>
<td>–</td>
</tr>
<tr>
<td>EBC</td>
<td>0.48 ± 0.06*</td>
<td>2.36 ± 0.09</td>
<td>5.67 ± 0.46</td>
<td>3.85 ± 0.01*</td>
<td>1.24 ± 0.05</td>
<td>2.23 ± 0.16</td>
<td>11.31 ± 0.11*</td>
<td>–</td>
</tr>
<tr>
<td>EFC</td>
<td>0.54 ± 0.06†</td>
<td>2.31 ± 0.06†</td>
<td>6.11 ± 0.42</td>
<td>3.92 ± 0.25†</td>
<td>1.31 ± 0.12</td>
<td>1.88 ± 0.21</td>
<td>5.68 ± 0.11</td>
<td>–</td>
</tr>
<tr>
<td>Sub-elite (All)</td>
<td>1.09 ± 0.03</td>
<td>2.84 ± 0.22</td>
<td>6.06 ± 0.65</td>
<td>9.30 ± 0.52</td>
<td>1.56 ± 0.18</td>
<td>3.78 ± 1.18</td>
<td>12.07 ± 0.28</td>
<td>–</td>
</tr>
<tr>
<td>SEBC</td>
<td>1.08 ± 0.07</td>
<td>2.97 ± 0.32</td>
<td>6.11 ± 0.67</td>
<td>9.08 ± 0.38</td>
<td>1.60 ± 0.26</td>
<td>4.24 ± 1.76</td>
<td>13.94 ± 0.66</td>
<td>–</td>
</tr>
<tr>
<td>SEFC</td>
<td>1.10 ± 0.05</td>
<td>2.73 ± 0.13</td>
<td>6.02 ± 0.64</td>
<td>9.48 ± 0.72</td>
<td>1.52 ± 0.08</td>
<td>2.28 ± 0.37</td>
<td>5.23 ± 1.70</td>
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</tr>
<tr>
<td><strong>Total Distance (m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite (All)</td>
<td>402 ± 15*</td>
<td>2184 ± 34*</td>
<td>2989 ± 42*</td>
<td>84 ± 15*</td>
<td>80 ± 12</td>
<td>131 ± 23</td>
<td>406 ± 13*</td>
<td>6276 ± 10</td>
</tr>
<tr>
<td>EBC</td>
<td>363 ± 4†</td>
<td>2142 ± 70†</td>
<td>2845 ± 16†</td>
<td>70 ± 26†</td>
<td>81 ± 2</td>
<td>122 ± 1</td>
<td>767 ± 28†</td>
<td>6390 ± 48</td>
</tr>
<tr>
<td>EFC</td>
<td>435 ± 23†</td>
<td>2208 ± 15†</td>
<td>3125 ± 57†</td>
<td>94 ± 9†</td>
<td>77 ± 22</td>
<td>160 ± 40</td>
<td>131 ± 2</td>
<td>6230 ± 26</td>
</tr>
<tr>
<td>Sub-elite (All)</td>
<td>548 ± 30</td>
<td>1786 ± 70</td>
<td>2040 ± 81</td>
<td>1173 ± 262</td>
<td>56 ± 8</td>
<td>110 ± 65</td>
<td>492 ± 17</td>
<td>6205 ± 491</td>
</tr>
<tr>
<td>SEBC</td>
<td>495 ± 28</td>
<td>1723 ± 87</td>
<td>1926 ± 268</td>
<td>952 ± 321</td>
<td>80 ± 10</td>
<td>189 ± 172</td>
<td>1004 ± 72</td>
<td>6369 ± 928</td>
</tr>
<tr>
<td>SEFC</td>
<td>586 ± 45</td>
<td>1804 ± 89</td>
<td>2112 ± 73</td>
<td>1329 ± 235</td>
<td>52 ± 7</td>
<td>45 ± 10</td>
<td>106 ± 43</td>
<td>6034 ± 321</td>
</tr>
</tbody>
</table>

EBC = Elite backcourt; EFC = Elite frontcourt; SEBC = Sub-elite backcourt; SEFC = Sub-elite frontcourt.

* Significant ($p < 0.05$) difference between elite and sub-elite players;

† Significant ($p < 0.05$) difference between EFC and SEFC players.
3.4 DISCUSSION

The aims of this study were to describe and compare the activity demands of elite and sub-elite open-age Australian male basketball competitions. Several significant differences in the match activity profiles between playing levels were identified. Specifically, elite players were required to complete greater workloads at moderate-high movement intensities, and in contrast, sub-elite players performed more maximal efforts, with greater recovery periods across matches. Furthermore, these differences were largely evident irrespective of positional role, suggesting that similar variations in match activity requirements between competition levels exist for both BC and FC players.

Many differences in movement frequencies were evident between playing levels, indicating that elite and sub-elite competitions elicit different intermittent profiles. Specifically, elite players performed significantly more total match movements (2743 ± 133) compared with their sub-elite counterparts (1972 ± 175). These results support previous research that suggested elite male basketball competition consists of extensive intermittent activity (changes in movement intensities) (Ben Abdelkrim et al. 2007; McInnes et al. 1995). However, the total movement frequencies presently observed across both levels of competition are much higher than those documented previously (997-1105 ± 27-183) (Ben Abdelkrim et al. 2007, 2010a; McInnes et al. 1995), most likely due to the inclusion of a more objective, velocity-based TMA methodology within the current study. The present research utilised a frame-by-frame objective analytical procedure, which is more sensitive to changes in speed and subsequently movement category than previous subjective TMA methodologies. Furthermore, the normalisation of sampling frequency during video analysis allowed for more accurate comparisons between playing levels and was unlikely to omit significant activity data considering the short duration between tracking points (80 ms).

Elite players in the present study performed a significantly greater number of standing/walking (794 ± 61 vs. 504 ± 42), jogging (937 ± 46 vs. 632 ± 65), and running (509 ± 31 vs. 339 ± 44) movements across match play than sub-elite players. These data strongly suggest that elite players exert a greater amount of energy accelerating and decelerating to
perform more match activities at varied movement intensities. Similar observations have been previously made during European basketball competitions (Ben Abdelkrim et al. 2010a).

Previously, junior international Tunisian players were reported to perform more total high-intensity (280 ± 54 vs. 198 ± 25) and overall movements (1105 ± 74 vs. 1004 ± 27) than national players across matches (Ben Abdelkrim et al. 2010a). These changes in movements have been suggested to heighten the physiological and metabolic demands placed on athletes in a variety of team sports (Greig et al. 2006; McInnes et al. 1995; Reilly, 1997). As such, advancements in basketball conditioning practices may include more intermittent-style training than previously thought. A greater emphasis on power and agility conditioning may benefit basketball-specific fitness through improving the repeated execution of acceleration and deceleration movements as required in elite competition.

Moreover, the greater frequencies of low shuffling (65 ± 5 vs. 36 ± 3), high shuffling (63 ± 7 vs. 28 ± 11) and upper-body movements (263 ± 8 vs. 220 ± 7) presently observed for elite competition compared with sub-elite competition indicate that an elevated physical load may be experienced at higher open-age playing levels. Previously, the performance of basketball-specific shuffling activity has been suggested to increase the physiological toll placed upon players during matches (McInnes et al. 1995). Further, the added recruitment of upper-body musculature has been reported to heighten the metabolic cost of various activities (Hoffman et al. 1996b). These findings would suggest that elite-level open-age basketball programs may necessitate a greater conditioning focus on shuffling-type and upper-body activity than lower playing levels.

Elite players in the present study displayed significantly shorter mean bout durations than sub-elite players within all movement categories except for running (see Table 3.2). These results support the previous observation that elite competition requires a greater intermittent workload than sub-elite competition, through spending shorter durations performing each movement before altering movement intensity.
Furthermore, the elite players in the current study spent significantly longer total durations performing jogging (1177 ± 11 s vs. 1013 ± 13 s) and running activity (703 ± 5 s vs. 456 ± 20 s) than sub-elite players. These results suggest that elite open-age male basketball players may be required to perform greater workloads at or above moderate movement intensities across matches compared with sub-elite players. This is further supported by the significantly greater total time spent standing/walking (1080 ± 65 s vs. 765 ± 18 s) and sprinting (120 ± 20 s vs. 11 ± 2 s) in sub-elite players. These differences indicate that sub-elite players spend more time performing maximal-intensity activity, and experience longer low-intensity periods through which they recover from these maximal bouts across competition.

The match activity differences between playing levels observed for open-age male basketball players in the present study have not been reported in junior male competitions (Ben Abdelkrim et al. 2010a). Previously, international junior male basketball players have been observed to spend a greater proportion of competition performing standing (13.9 ± 2.1% vs. 11.5 ± 2.7%), walking (14.2 ± 1.3% vs. 13.4 ± 1.4%), and sprinting activity (6.0 ± 1.0% vs. 4.9 ± 1.2%) and less time performing running (10.2 ± 0.8% vs. 11.2 ± 1.0%) and jogging activity (11.3 ± 1.6% vs. 12.0 ± 0.9%) than national players. These differences were attributed to the greater training and conditioning requirements within international junior basketball competition (Ben Abdelkrim et al. 2010a). Similarly, the present differences may be due to differences in player fitness between competition levels. However, the effects of other factors, such as match structure and decision-making may further explain the match activity variations between elite and sub-elite open-age male basketball competitions.

Elite competition may be more structured than sub-elite matches, with players required to constantly move through offensive sets and stay active defensively at moderate movement intensities to a greater extent. Conversely, sub-elite competition may involve less structure, with players performing or defending explosive isolated movements or moving at low activity intensities while waiting for involvement. This suggestion is supported by the
greater mean bout (4.28 ± 0.32 s vs. 3.95 ± 0.36 s) and total duration (309 ± 21 s vs. 266 ± 8 s) for dribbling activity in sub-elite backcourt players compared with elite backcourt players. These findings suggest that possession of the ball is less distributed during sub-elite competition which may result in less intense activity being performed by many players during these periods. Furthermore, the decision-making of elite players may be more advanced than sub-elite players, which could allow for more effective positioning during various playing phases. As such, elite players may require less maximal efforts to regain appropriate position on the court, as supported by the significantly lower frequency of sprinting bouts presently reported during elite competition compared with the sub-elite level (125 ± 21 vs. 22 ± 3).

A number of similarities and differences are apparent between the present results and past research (Ben Abdelkrim et al. 2007; Bishop & Wright, 2006; McInnes et al. 1995). Previously, McInnes et al. (1995) reported elite Australian male players to spend 50%, 35%, and 15% of match play duration performing LIA, MIA, and HIA. Furthermore, more recent investigations reported variations to these proportions in elite male British (53%, 41%, and 6%), and international (53%, 24%, and 20%) and national (51-72%, 17-31%, and 11-16%) junior Tunisian male basketball players (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006). Conversely, the present findings demonstrate elite and sub-elite open-age Australian male players spent 31%, 67%, and 2%, and 42%, 53%, and 5% within these categories. Differences between the movement intensity proportions observed within the present data and those reported previously are likely due to competition constraints as well as disparities in the TMA methodologies used.

Within previous studies, a number of major differences in movement categorisation are evident compared with the present methodology. Bishop et al. (2006) only included three movement categories (LIA, MIA, and HIA) with broad definitions and Ben Abdelkrim et al. (2007) identified jogging movements as LIA. Furthermore, McInnes et al. (1995) and Ben Abdelkrim et al. (2007) included jumping, striding, sideways running, and positioning as HIA and three movement categories of shuffling activity. Conversely, within the present study,
jogging was included as MIA, jumping, striding, and positioning were not included in time and distance calculations, and only two categories of shuffling (high and low) were used. In addition, the present investigation is the first to include ball dribbling movements, which was not analysed according to intensity and therefore not included in activity intensity breakdowns. These methodological differences should be considered when comparing the present results with previous findings.

When interpreting the live time proportion of activity intensity according to competition level within the present results, elite players performed MIA 14% longer than sub-elite players across matches. However, sub-elite players spent 11% and 3% greater match time performing standing/walking and sprinting activity than elite players during competition. These differences illustrate the extent of the variation in demands between competition levels, and strengthen the suggestion that elite competition requires players to sustain work rates at or above moderate movement intensities during match play more than sub-elite competition.

The TMA methodology used in the present study allowed the calculation of mean bout and total distances travelled by the elite and sub-elite players. Elite (6276 ± 10 m) and sub-elite players (6205 ± 491 m) covered similar total distance workloads during total live match time. However, elite players travelled further distances (5173 ± 8 m) performing MIA than sub-elite players (3826 ± 146 m) across matches. In contrast, sub-elite players travelled greater distances executing LIA (604 ± 24 m vs. 484 ± 4 m) and HIA (1283 ± 321 m vs. 215 ± 8 m). Taken together, these results support the observation that within open-age Australian basketball competition, elite players are required to cover more distance at moderate movement intensities than sub-elite players.

Previously, distances travelled by basketball players during competition have not been frequently reported (Ben Abdelkrim et al. 2010b; Erculj et al. 2008). It has been suggested that the measurement of total distance workloads can lead to erroneous interpretations of match demands during basketball competition (McInnes et al. 1995). However, the measurement of distances covered performing at moderate-high movement intensities may
provide useful data for basketball coaches, players, and conditioning staff (Ben Abdelkrim et al. 2010b; Ziv & Lidor, 2009).

Previously, Erculj et al. (2008) demonstrated that elite male Slovenian players covered an average of 4.40 km across 40-min matches using an extrapolation calculation. Whilst these data were not categorised into different movement intensities, it is considerably less (~19%) than the total distances travelled by players in the current study relative to each minute of live match time. This suggests that the competitions in the current study required players to exert greater activity intensities across matches than the Slovenian League included in the aforementioned research, and highlight the differences in competition activity demands that are likely to exist between different geographical regions. Variations in the TMA methodologies used by Erculj et al. (2008) to those employed in the present research must also be acknowledged, and may have contributed to the observed differences in player distance coverage across matches.

More recently, Ben Abdelkrim et al. (2010b) reported elite junior Tunisian male basketball players to cover 7.56 ± 0.58 km across competitive matches. Specifically, players travelled 1.72 ± 0.14 km, 1.87 ± 0.32 km, 0.93 ± 0.16 km, 0.41 ± 0.11 km, 0.76 ± 0.17 km, and 1.47 km walking, jogging, running, striding, sprinting, and shuffling. The present results indicate that open-age Australian male basketball competition may involve less shuffling activity (167-214 m) and more running activity (2040-2989 m) than junior Tunisian male competition. These disparities may be due to variations in tactical strategies and player conditioning between the teams and competitions, as well as differences in movement categorisation and analytical methodologies used. Furthermore, the overall mean distance travelled by junior Tunisian players was greater than that presently observed for open-age Australian players. This is most likely due to the variations in analysis time, with previous research examining player activity during all match stoppages except time-outs and inter-quarter breaks (Ben Abdelkrim et al. 2010b). This is further supported by the greater amount of walking activity observed within these data compared with the current results (402-548 m), considering that players are unlikely to be engaged in HIA during these
stoppages. As such, caution should be taken when comparing the results of the present study to those of previous research.

Throughout the present study, a number of limitations were recognised. Firstly, the present findings are only indicative of the teams and competitions investigated. Furthermore, the player activity was only examined across a limited number of matches (elite: n = 2; sub-elite: n = 3). Future studies should examine multiple teams and competitions across more matches to gather greater information concerning the demands of the basketball match play. Secondly, movement was not categorised according to direction. Given that multi-directional running has previously been reported to elicit higher physiological and metabolic loads than straight line running (Reilly & Bowen, 1984; Williford et al. 1998), the lack of direction-specificity included in the present methodology should be considered when interpreting the results. Thirdly, activity categorisation was based on generalised velocity bands and developed irrespective of team role. More precise activity data could have been gathered if categorisation for each player was based on proportions of individual maximal sprint velocity and determined according to offensive and defensive play phases. Fourthly, the TMA methodology used in this study did not allow the calculation of player accelerations and decelerations. The provision of these data would present greater insight into activity loads placed upon players across competitive matches. Future basketball TMA research could incorporate the use of additional technologies such as accelerometry or advanced analytical software to provide these data. Finally, the current study did not include any physiological measurements across matches due to competition constraints. For a more comprehensive comparison of match demands between competition levels, future basketball research should include both physiological and TMA measures.
3.5 CONCLUSION

This study provides the first known description and comparison of the activity demands for current elite and sub-elite open-age male basketball competitions, both within Australia and internationally. The present results strongly suggest that elite male basketball players are required to perform more extensive intermittent activity and exert greater sustained movement intensities compared with sub-elite players. This was evidenced by elite players experiencing significantly more changes in movement intensities, and performing significantly more jogging and running activity than sub-elite players. In contrast, the maximal activity demands may be higher in sub-elite competition as shown by significantly greater sprinting requirements within this playing level. However, these players also experienced significantly longer periods of LIA to recover from these maximal bouts. These differences may reflect disparities in player conditioning between playing levels. Additionally, other factors such as team tactics, match structure, and skill level may have influenced the observed match activity demands across elite and sub-elite playing levels.

3.6 PRACTICAL APPLICATIONS

The present data offer many practical benefits to basketball coaches, players, and conditioning staff. Firstly, these findings suggest that more attention may need to be given to intermittent and agility conditioning as well as maintaining moderate-high work intensities within basketball programs than previously reported. Secondly, the present results could allow more precise, match-specific training plans to be developed for both elite and sub-elite male basketball players. Finally, the comparative data may be used by sub-elite coaches and conditioning specialists to emphasise the demands of higher competition, which may facilitate the transition of younger players to the elite level and assist in the development of more effective talent identification procedures within the sport.
Chapter 4

The intra-match activity variation during elite and sub-elite open-age Australian male basketball competitions

Submitted for publication:
Scanlan, A., Dascombe, B. & Reaburn, P. (In review). The intra-match activity variation during elite and sub-elite open-age Australian male basketball competitions.
4.0 ABSTRACT

The aims of this study were to describe the intra-match activity variation during current open-age Australian male basketball competition and compare these changes between playing levels. Video-based time-motion analyses were conducted on elite (n = 10; age: 28.3 ± 4.9 yr; stature: 197.4 ± 8.3 cm; body mass: 97.0 ± 13.9 kg) and sub-elite (n = 12; 26.1 ± 5.3 yr; 191.4 ± 7.6 cm; 85.9 ± 13.2 kg) Australian basketball players across multiple (n = 2, 3) competitive matches. Movement frequencies, total durations (s), total distances (m), and mean velocities (m∙s⁻¹) were calculated for low-intensity, high-intensity, shuffling, and dribbling movements. Movement frequencies only were calculated for jumping and upper-body activity. Elite players experienced large declines (11-17%, effect size (ES) = 1.2-3.1) in HIA workloads, whereas sub-elite players encountered small increases (1-6%, ES = 0.1-0.3) across matches. These differences may have been due to the strategic play of the elite players and competition constraints of sub-elite matches. Elite players travelled at significantly lower dribbling (Quarter (Q) 1: 3.09 ± 0.03 m∙s⁻¹; Q3: 2.81 ± 0.01 m∙s⁻¹, p = 0.029) and total activity velocities (Q1: 2.22 ± 0.04 m∙s⁻¹; Q3: 2.09 ± 0.03 m∙s⁻¹, p = 0.021) during the third quarter of play compared to the first quarter. As such, an increased control of ball possession may have slowed the activity pace during the later stages of elite competition. Moderate-large increases in stoppage duration during the second (24%, ES = 0.7) and fourth quarters (60%, ES = 1.5) compared to the first and third quarters of play were observed across sub-elite competition. These increased recovery periods with match progression may have permitted enhanced maintenance of HIA across competition within sub-elite players. This assumption is supported by a large correlation (r = 0.614, p = 0.034) between stoppage duration and mean HIA velocity for sub-elite players across match quarters. The present findings suggest that match activity demands vary across open-age Australian male basketball competition and may be influenced by playing level.

Key words: team sports performance; time-motion analysis; intermittent exercise.
4.1 INTRODUCTION

Basketball is an international team-based sport that is played across many competition levels from recreational to elite. In recent times, several researchers have attempted to quantify the activity demands of male basketball competition using video-based time-motion analysis (TMA) technology (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Janeira & Maia, 1998; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). However, these studies investigated player activity during preseason/practice matches (McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006) and following outdated rules (Janeira & Maia, 1998; McInnes et al. 1995). As such, limited data exist that describe the activity demands of open-age male basketball players during competitive match play under contemporary match constraints.

Previously, basketball competition activity has been described over entire matches, with changes in movement type reported to occur every ~2 s of playing time (Ben Abdelkrim et al. 2007). Additionally, male basketball players have been reported to spend varied proportions of total live match time performing at low (53-72%), moderate (17-43%), and high intensities (6-20%) during actual competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006). Taken together, these observations underscore the highly intermittent workload imposed upon basketball players across matches, a characteristic indicative of most court-based team sports (Barbero-Alvarez et al. 2008; Davidson & Trewartha, 2008). However, total activity demands provide little detail concerning the variation in activity workloads that may occur across each of the playing periods during matches.

The determination of changes in activity demands, specifically high-intensity activity (HIA), across playing periods has been suggested to offer the greatest insight into the effects of match-related fatigue during team sport competition (Coutts et al. 2009; Rampinini, Coutts, Castagna, Sassi & Impellizzeri, 2007b). Previously, variations in activity workloads have been frequently reported between match periods across basketball competition (Ben Abdelkrim et al. 2010a, 2010b, 2007; Janeira & Maia, 1998). Earlier, Janeira and Maya (1998) reported
significant reductions in high-intensity running distance (20%) and jumping frequency (12%) during the second half of elite male basketball competition compared to the first half. More recently, a large decline in the proportion of HIA performed during the fourth quarter (9-14%) compared to the first and second quarters was observed in junior elite Tunisian male basketball players (Ben Abdelkrim et al. 2007). A similar cohort of Tunisian players also demonstrated a significant reduction in HIA distance travelled in the second half of play (945 ± 195 m) compared to the first half (798 ± 150 m) (Ben Abdelkrim et al. 2010b).

The reported HIA declines during later match periods across basketball competition have been attributed to both fatigue-related mechanisms and tactical play, including an increased offensive control and reduced occurrence of fast break transitions (Ben Abdelkrim et al. 2007). Moreover, basketball match play involves frequent match stoppages due to competition constraints, including time-outs, free-throw shooting, player fouls, and out-of-bounds instances. The quantity of stoppage time encountered across basketball competition is likely to influence the available recovery opportunity for players. This may in turn influence the fatigue responses and activity demands experienced by basketball players across match periods (McInnes et al. 1995).

While changes in match activity across playing periods have been frequently observed during male basketball competition, previous observations have only been made following superseded match rules (Janeira & Maia, 1998) and within junior players (Ben Abdelkrim et al. 2010a, 2010b, 2007). Given that open-age basketball players have been reported to possess superior anthropometric and fitness attributes to junior athletes (Ben Abdelkrim et al. 2010c), existing findings may not be applicable to current open-age basketball competition. At present, no data exist detailing and comparing intra-match activity changes in elite and sub-elite open-age male basketball competitions. Thus, the aims of this study were to describe the variation in activity demands experienced across the four playing periods in open-age Australian male basketball competition and compare these changes between elite and sub-elite playing levels.
4.2 METHODS

4.2.1 Participants

Elite male players competing within the National Basketball League (NBL) (n = 10; age: 28.3 ± 4.9 yr; stature: 197.4 ± 8.3 cm; body mass: 97.0 ± 13.9 kg) and sub-elite male players competing within the Queensland Basketball League (QBL) (n = 12; 26.1 ± 5.3 yr; 191.4 ± 7.6 cm; 85.9 ± 13.2 kg) volunteered to participate in this research. Within Australia, the NBL is the highest level of competition, while the QBL forms part of a second-tier state competition played during different periods of the year. Prior to participation, all players had completed independent pre-season conditioning programs consisting of a combined training plan of agility, plyometric, anaerobic, and endurance components. All players were completing three sessions of training (~6 h total), and participating in a maximum of two competitive matches per week for the duration of the study. During the weeks of video data collection, only one match was completed. Informed consent was obtained from all participants, and research procedures were granted prior approval by the CQU University Human Research Ethics Committee.

4.2.2 Procedures

A within-subjects research design was employed to examine the effects of time across basketball match play. The present study used video-based procedures to capture player activity during competition. Elite players were filmed across two competitive matches, one at mid-season and one towards the end of the competitive season. Sub-elite player activity was collected across three competitive matches throughout the regular playing season. All matches consisted of 4 x 12-min quarters, with 2-min inter-quarter breaks and a 10-min half-time break.

Due to physical limitations of the playing stadia, different video capture methods were used for each playing group. All video data for the elite players were collected using a JVC Everio GZ-HD10 colour camcorder (Hagemeyer, Kingsgrove, Australia) with a JVC GL-AT30 telephoto conversion lens (Hagemeyer, Kingsgrove, Australia). The camera was in a fixed position at the half-way point of the court at a height (~20 m) and distance (~12 m) from the
sideline so that all player activity could be recorded in one view. Recordings of elite matches were taken at a sample rate of 25 Hz. Video data for the sub-elite players were collected using two wide-angle Basler A602FC colour cameras (Basler Vision Technologies, Ahrensburg, Germany). Each camera was fixed as close as possible to the half-way line at a height (~6 m) and distance (~2 m) to capture all activity within one half of the court. Both cameras were synchronised during all sub-elite video recordings and data were sampled at a rate of 7.5 Hz to allow for adequate storage of data onto a computer.

Following video capture, the frame rate of each video file was normalised. Frame-by-frame analysis was utilised to determine player activity using a customised tracking system (Labview™, National Instruments, Texas, USA). The operator manually identified the location of each player within each frame during the analysis. Each camera view was calibrated prior to each analysis using a four-point transformation involving pre-measured distance dimensions of the playing area. This allowed reconstruction of the collected images to account for perspective errors associated with the different camera views. Movement velocity (m∙s⁻¹) was calculated using the determined distance data and the time between player tracking points.

Players were filmed for entire matches including all stoppages in play. Data from substituted players were cumulated within the five on-court playing positions across matches. Activity measures were averaged across all playing positions for each match and analysed only during live time (Ben Abdelkrim et al. 2007). Activity categorisation was based on movement velocities as per previous court-based team sport TMA research (Barbero-Alvarez et al. 2008). The following activity categories were measured:

1. **Standing/walking**: multi-directional movement performed at a velocity of 0-1.0 m∙s⁻¹, when not in a defensive stance.
2. **Jogging**: multi-directional movement performed at a velocity of 1.1-3.0 m∙s⁻¹, when not in a defensive stance.
3. **Running**: multi-directional movement performed at a velocity of 3.1-7.0 m∙s⁻¹, when not in a defensive stance.
4. Sprinting: multi-directional movement performed at a velocity of >7.0 m∙s⁻¹, when not in a defensive stance.

5. Low shuffling: any multi-directional movement performed strictly in a defensive stance position at a velocity of ≤2.0 m∙s⁻¹.

6. High shuffling: any multi-directional movement performed strictly in a defensive stance position at a velocity of >2.0 m∙s⁻¹.

7. Dribbling: any movement in which a player is actively in possession of and dribbling the ball in any direction.

8. Jumping: any movement or activity whereby a player initiates a jumping action and breaks feet contact with the playing surface. This activity was recorded as a discrete movement with no duration or distance data calculated.

9. Upper-body movements: any upper-body action that involves the raising of one or both arms above the horizontal. These movements were analysed both independently of and simultaneously with other movements, apart from shuffling and dribbling activity. This activity was recorded as a discrete movement.

Player activity was further analysed according to low-intensity activity (LIA) (standing/walking and jogging) and HIA (running and sprinting). Similar activity intensity bands have been used in previous team sport TMA studies (Coutts et al. 2009; Sirotic et al. 2009). Additionally, all shuffling intensities were grouped as one category for ease of comparison between playing periods. The determination of discrete (jumping and upper-body activity) and shuffling movements was based on the subjective interpretation of the researchers (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Mean frequency, total duration spent (s), and total distance travelled (m) in each movement category were calculated across each match quarter. Mean movement velocity (m∙s⁻¹) was also calculated for low-intensity, high-intensity, shuffling, dribbling, and overall activity within each quarter. All activity categories were calculated using multi-directional analysis, including backward and forward motion, and lateral motion (when not deemed to be shuffling). Further,
stoppage time was calculated as the difference between total time and live time within each quarter for each playing level.

All video analyses were performed by a single member of the research team. The intra-tester reliability of the present TMA methodology has been deemed acceptable with all measures having displayed adequate intra-tester reliability (CV = 0-14%; ICC = 0.84-1.00) for both elite and sub-elite analyses.

### 4.2.3 Statistical Analyses

Means (± SD) were determined for all descriptive and activity measures. Shapiro-Wilks Test and Levene’s Test for equality verified the normality and homogeneity of variance of the present data prior to parametric analysis. Multiple Analysis of Variance (MANOVA) were used to identify any significant differences in activity measures between playing periods for each competition level. Bonferroni post-hoc comparisons were utilised to locate the sources of any observed significant differences. Cohen’s $d$ was calculated to determine the effect size (ES) between playing periods using the following criteria: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and >2.0, very large (Hopkins, 2002). Pearson Product Moment Correlation Coefficients (r) were also calculated to measure the relationships between stoppage time and activity measures across match quarters. The criteria used to interpret correlation strength included: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; and 0.9-1.0, almost perfect (Hopkins, 2002). All statistical analyses were performed using the spreadsheet methods of Hopkins (2000b), Microsoft Excel™ (Microsoft, Redmond, Washington, USA), and Statistical Package for Social Sciences (SPSS) software (Version 17.0, SPSS Inc., Chicago, Illinois, USA). Statistical significance was accepted at $p \leq 0.05$. 
4.3 RESULTS

The results for movement frequency within each activity category for elite and sub-elite players across match quarters are presented in Table 4.1. Additionally, the total durations (s) spent and total distances (m) covered within each activity category across match quarters for each playing level are displayed in Table 4.2.

Inter-quarter comparisons revealed no statistically significant differences within the frequency, duration, and distance data for either competition level. However, ES analyses showed elite players underwent large declines in HIA bout frequency during the third (17%, $ES = 1.7$) and fourth quarters (11%, $ES = 1.2$) compared to the first quarter. Moreover, very large reductions in total time spent (14%, $ES = 2.9$) and distance travelled (17%, $ES = 3.1$) executing HIA were apparent across the fourth quarter compared to the first quarter for elite players. In contrast, sub-elite players exhibited small increases in HIA frequency (5%, $ES = 0.3$) and total distance (1%, $ES = 0.1$) between the first and fourth quarters.

The results for mean movement velocity with each activity category for elite and sub-elite players are displayed in Figure 4.1. Inter-quarter comparisons revealed elite players worked at significantly reduced dribbling ($F_{3,4} = 9.192$, $p = 0.029$, $ES = 17.7$) and total movement velocities ($F_{3,4} = 11.173$, $p = 0.021$, $ES = 5.2$) during the third quarter compared to the first quarter.

No statistically significant differences in stoppage time were apparent between quarters for elite and sub-elite players. However, effect size calculations revealed sub-elite players experienced moderate-large increases in stoppage time during the second (24%, $ES = 0.7$) and fourth quarters (60%, $ES = 1.5$) compared to the first and third quarters. Conversely, elite players encountered small-very large decrements in stoppage time (6-24%, $ES = 0.3-2.7$) during the fourth quarter compared to each of the other match periods. Moreover, moderate ($r = 0.427$) and large ($r = 0.614$, $p = 0.034$) relationships were present between stoppage time and total HIA duration and HIA mean velocity across match quarters for sub-elite players (see Figure 4.2).
Table 4.1: The mean (± SD) frequencies of various movements performed by elite (n = 2) and sub-elite (n = 3) open-age Australian male basketball players across match quarters.

<table>
<thead>
<tr>
<th></th>
<th>LIA</th>
<th>HIA</th>
<th>Shuffle</th>
<th>Dribble</th>
<th>Jump</th>
<th>Upper-body</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>444 ± 53</td>
<td>146 ± 16</td>
<td>38 ± 2</td>
<td>9 ± 0</td>
<td>13 ± 0</td>
<td>65 ± 3</td>
<td>715 ± 73</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>281 ± 30</td>
<td>114 ± 7</td>
<td>21 ± 8</td>
<td>9 ± 0</td>
<td>11 ± 0</td>
<td>56 ± 2</td>
<td>492 ± 43</td>
</tr>
<tr>
<td>Quarter 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>436 ± 37</td>
<td>134 ± 10</td>
<td>31 ± 1</td>
<td>11 ± 0</td>
<td>13 ± 1</td>
<td>68 ± 3</td>
<td>693 ± 42</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>286 ± 35</td>
<td>118 ± 12</td>
<td>15 ± 3</td>
<td>11 ± 1</td>
<td>11 ± 1</td>
<td>54 ± 4</td>
<td>495 ± 42</td>
</tr>
<tr>
<td>Quarter 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>418 ± 23</td>
<td>121 ± 13</td>
<td>33 ± 6</td>
<td>10 ± 0</td>
<td>11 ± 1</td>
<td>65 ± 4</td>
<td>658 ± 37</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>278 ± 21</td>
<td>112 ± 22</td>
<td>15 ± 4</td>
<td>10 ± 1</td>
<td>12 ± 1</td>
<td>56 ± 7</td>
<td>483 ± 50</td>
</tr>
<tr>
<td>Quarter 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>433 ± 6</td>
<td>130 ± 11</td>
<td>26 ± 5</td>
<td>11 ± 2</td>
<td>12 ± 1</td>
<td>66 ± 4</td>
<td>678 ± 19</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>291 ± 23</td>
<td>120 ± 26</td>
<td>13 ± 1</td>
<td>10 ± 2</td>
<td>12 ± 1</td>
<td>54 ± 3</td>
<td>500 ± 52</td>
</tr>
</tbody>
</table>

LIA = Low-intensity activity; HIA = High-intensity activity.
Table 4.2: The mean (± SD) total durations (s) spent and total distances (m) covered performing various movements by elite (n = 2) and sub-
elite (n = 3) open-age Australian male basketball players across match quarters.

<table>
<thead>
<tr>
<th></th>
<th>Total duration (s)</th>
<th>Total distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LIA</td>
<td>HIA</td>
</tr>
<tr>
<td>Quarter 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>483 ± 3</td>
<td>193 ± 13</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>510 ± 24</td>
<td>146 ± 11</td>
</tr>
<tr>
<td>Quarter 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>485 ± 4</td>
<td>183 ± 4</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>523 ± 43</td>
<td>148 ± 10</td>
</tr>
<tr>
<td>Quarter 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>490 ± 6</td>
<td>171 ± 12</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>521 ± 13</td>
<td>144 ± 19</td>
</tr>
<tr>
<td>Quarter 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>496 ± 20</td>
<td>166 ± 2</td>
</tr>
<tr>
<td>Sub-elite</td>
<td>546 ± 23</td>
<td>145 ± 28</td>
</tr>
</tbody>
</table>

LIA = Low-intensity activity; HIA = High-intensity activity.
Figure 4.1: The mean movement velocities (m·s⁻¹) for various activities across match quarters during (A) elite (n = 2) and (B) sub-elite (n = 3) open-age Australian male basketball competitions.
LIA = Low-intensity activity; HIA = High-intensity activity.
* Significantly (p < 0.05) different from quarter 1.
Figure 4.2: Scatterplots displaying the relationships between stoppage time (s) and (A) total activity duration (s) and (B) mean movement velocity (m∙s⁻¹) performing high-intensity activity across match quarters during elite (n = 8) and sub-elite open-age Australian male competitions (n = 12). *p < 0.05.
4.4 DISCUSSION

The present study detailed the intra-match activity variation across the four playing periods within current elite and sub-elite male basketball competitions. Such data have not been previously provided for Australian or open-age male basketball competition. The present findings suggest that the activity demands of Australian open-age male basketball competition change progressively over the course of a match. Moreover, the current data demonstrate that elite players experienced reduced high-intensity running and dribbling velocities after the first quarter of play. In contrast, sub-elite players performed at similar work intensities across match quarters, possibly due to an increase in stoppage time during the latter quarters of match halves. Taken together, these results suggest that fatigue mechanisms, tactical play, and competition constraints may influence the activity patterns of open-age Australian male basketball players towards the end of competitive match play.

The reductions in HIA and total activity workloads during the later stages of elite basketball matches observed in this study are in agreement with previous research examining elite junior male basketball players (Ben Abdelkrim et al. 2010a, 2010b, 2007; Janeira & Maia, 1998). Previously, a number of physiological responses have been suggested to contribute to player fatigue and subsequent reductions in activity work rates during male basketball competition, including muscle glycogen depletion, temperature elevation, dehydration, muscle damage, and player fitness (Ben Abdelkrim et al. 2010a). Given that fatigue associated with basketball activity has been defined as an inability to maintain the demands of play (Montgomery et al. 2008b), the present workload reductions in elite open-age male basketball competition may be due to these fatigue-related responses. However, considering that the activity data in the present study was calculated inclusive of all substituted players, this suggestion remains to be elucidated.

In addition to fatigue-related responses, the role of tactical play has been suggested to contribute to reduced activity intensities observed across basketball competition (Ben Abdelkrim et al. 2007). Ben Abdelkrim et al. (2007) suggested that teams are more likely to control the ball towards the end of competition, which limits the opportunity of high-
intensity play transitions and the maintenance of fast match paces. The use of such a tactical strategy is supported by the present findings, as elite players performed at significantly lower dribbling (Quarter (Q)1: 3.09 ± 0.03 m∙s⁻¹; Q2: 3.01 ± 0.10 m∙s⁻¹; Q3: 2.81 ± 0.01 m∙s⁻¹; Q4: 2.90 ± 0.05 m∙s⁻¹) and total activity velocities (Q1: 2.22 ± 0.04 m∙s⁻¹; Q2: 2.16 ± 0.09 m∙s⁻¹; Q3: 2.09 ± 0.03 m∙s⁻¹; Q4: 2.11 ± 0.01 m∙s⁻¹) during the later stages of matches. The significant decrements in dribbling intensity for the elite players towards the end of match play may represent an increased control of possession through the coordination of offensive plays, as opposed to employing faster dribbling velocities during quick play transitions. Furthermore, the large mean winning margin (27 ± 6 points) evident for the elite team indicates that the slower total activity velocities across the final quarters of competition may correspond with an attempt to limit opposition scoring opportunities and protect match score-lines. However, future research is needed examining the activity changes across playing periods during various competition situations with match-related statistics to justify these suggestions.

The small variation in activity intensities during sub-elite matches may be explained by the correlations evident between stoppage time and HIA measures across match quarters (see Figure 4.2). Previously, similar match stoppage times have been observed between junior international and national Tunisian basketball competitions (Ben Abdelkrim et al. 2010a). However, the sub-elite players in the present study experienced considerably larger (50%) stoppage durations across the final quarter than elite players. Furthermore, stoppage time increased during the final quarters of each half (24-60%) during sub-elite competition. Both tactical and competition factors may have contributed to this difference in stoppage time between playing levels, including the use of time-outs and incidence of player fouls. Nevertheless, the increased opportunity for passive recovery by the sub-elite players during match stoppages may have led to increased restoration of phosphocreatine and adenosine triphosphate stores, possibly resulting in an enhanced ability to maintain HIA workloads across matches (Dupont et al. 2003). Such passive recovery periods have previously been
observed to offer the most benefit in reducing fatigue and improving repeated sprint performance in basketball players (Castagna et al. 2008a).

Pacing strategies may have also been used by sub-elite players and possibly contributed to the observed activity variations across matches (Coutts et al. 2008). In the present study, sub-elite players performed at slower LIA velocities across match periods following the first quarter (Q1: 1.14 ± 0.02 m·s⁻¹; Q2: 1.12 ± 0.04 m·s⁻¹; Q3: 1.10 ± 0.03 m·s⁻¹; Q4: 1.11 ± 0.08 m·s⁻¹). Further, these LIA velocities were considerably smaller than those evident for elite players (Q1: 1.36 ± 0.01 m·s⁻¹; Q2: 1.32 ± 0.04 m·s⁻¹; Q3: 1.29 ± 0.02 m·s⁻¹; Q4: 1.36 ± 0.04 m·s⁻¹). Previously, the reduction of activity intensities during slower velocity movements have been suggested to allow the maintenance of HIA output with match progression during team sports (Duffield, Coutts & Quinn, 2009). Furthermore, Castagna et al. (2008a) recommended basketball players to limit unnecessary activity across competition to uphold HIA performance with match progression. Thus, the reduced LIA velocities observed for sub-elite players in the present study may have contributed to the maintenance of high work intensities across match periods within this group.

While fatigue-related responses, tactical decisions, and competition constraints may explain the present variations in match activity requirements during open-age Australian male basketball competition, other factors should also be considered. Previously, style of play (Bishop & Wright, 2006), skill-level (Coelho E Silva et al. 2008), match importance, and playing experience (Edwards & Noakes, 2009) have been suggested to affect player activity workloads across team sport competition. Therefore, these aspects should be acknowledged when interpreting the present results.

A number of limitations were identified within the current study. Firstly, player activity was not described with direction of movement, which has been suggested to produce varied physiological and metabolic demands (Reilly, 1997). Secondly, the velocity ranges used for movement categorisation during methodology development were based on previous generalised values described in court-based team sports (Barbero-Alvarez et al. 2008). A more specific individualised approach should be addressed in future basketball TMA
research. Thirdly, player activity was only examined across a limited number of matches (elite: n = 2; sub-elite: n = 3) and calculated irrespective of playing position. Future studies should examine changes in player activity relative to playing position across a greater number of matches to gather more precise information concerning the demands of the basketball match play. Finally, these findings are only indicative of the teams investigated, and changes in match activity demands across competition are likely to vary in other teams and leagues due to differences in player fitness and skills, match score and importance, opponent ability, and refereeing decisions. Future investigations might analyse multiple teams and leagues to gather a definitive understanding of the intra-match activity variation during open-age male basketball competition.

4.5 CONCLUSION
In summary, the present study is the first to quantify and compare the activity variation over the four quarters of a match during elite and sub-elite open-age Australian basketball competitions. The results suggest that elite basketball players experience greater reductions in HIA towards the end of matches when compared with sub-elite players. These differences may have been due to greater fatigue responses and tactical strategies reducing the pace of match activity towards the end of elite competition. In contrast, increased stoppage durations across sub-elite competition may have permitted larger passive recovery time and improved maintenance of HIA across match periods within these players.

4.6 PRACTICAL APPLICATIONS
The current findings offer important practical value to the sport of basketball. Firstly, these data may aid the development of more precise player conditioning programs at both the elite and sub-elite levels. Secondly, the comparisons between competition levels may facilitate the progression of developmental players to higher playing standards (Brewer et al. 2010). Finally, these findings suggest that tactical and player management strategies across playing periods may influence the activity profiles and maintenance of HIA outputs during matches within elite and sub-elite basketball competitions.
Chapter 5

The Basketball Exercise Simulation Test: A match-specific physical fitness test for basketball players

Submitted for publication:

5.0 ABSTRACT

The purpose of this study was to develop a reliable and valid field test that simulates the match-specific activity demands of male basketball competition. Open-age Australian male basketball players (age: 22.1 ± 6.6 yr; stature: 187.2 ± 8.2 cm; body mass: 89.4 ± 11.0 kg; body fat: 20.0 ± 6.6%) competing within state- and regional-level competitions participated in the present research. The Basketball Exercise Simulation Test (BEST) was developed using notational data describing the activity demands of elite open-age Australian male basketball competition. Participants completed a repeat-sprint protocol, Yo-Yo Intermittent Recovery Test (Yo-Yo IR1), and 12-min trial of the BEST. Nine participants completed a further trial of the BEST separated by at least 7 days. Measures taken across the BEST included mean HR (b∙min⁻¹), sprint decrement (%), mean sprint and circuit time (s), and total distance covered (m). Test-retest reliability was determined by calculating the Intra-class Correlation Coefficient (ICC), Typical Error of Measurement (TEM), Coefficient of Variation (CV), and 95% Confidence Intervals (CI) across the two BEST trials. Criterion validity was calculated using Pearson Correlation analysis between each BEST measure and performance in the repeat-sprint protocol and Yo-Yo IR1. Mean sprint and circuit time, and sprint decrement displayed strong reliability (ICC = 0.93-0.99), while all measures except sprint decrement (CV = 14.6%) exhibited high CV (<5%). Significant (p < 0.05) relationships were reported between mean sprint and circuit time, and sprint decrement during the BEST and repeat-sprint performance (r = 0.81-0.92), as well as Yo-Yo IR1 distance (r = -0.71-0.85). Mean sprint time appeared to be the most reliable and valid BEST performance measure. The present results suggest that the BEST is a reliable and valid match-specific test for the assessment and monitoring of basketball-related anaerobic and aerobic fitness.

Key words: team sport; field test; intermittent performance.
5.1 INTRODUCTION

The activity requirements of basketball have been characterised as highly intermittent, with extensive involvement of both the anaerobic and aerobic energy systems (Ben Abdelkrim et al. 2007; Bishop & Wright, 2006; McInnes et al. 1995). These demands have been previously quantified across different male basketball competitions using time-motion analysis (TMA) techniques (Ben Abdelkrim et al. 2010a, 2010b, 2007; Bishop & Wright, 2006; Janeira & Maia, 1998; McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006). However, the objective activity demands for open-age male players during current competition have only recently been described in detail by the present authors (see Studies One and Two), with previous research describing these demands following outdated match rules (Janeira & Maia, 1998; McInnes et al. 1995), within age-restricted playing populations (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2006), during pre-season/practice matches (McInnes et al. 1995; Narazaki et al. 2009; Tessitore et al. 2006), and using limited movement intensities (Bishop & Wright, 2006).

Previously, TMA data have been utilised for the development of several laboratory- and field-based exercise protocols that simulate the demands of competition within a number of team sports including soccer (Nicholas et al. 2000; Oliver et al. 2007; Williams et al. 2009; Wragg et al. 2000), rugby league (Holloway et al. 2008), rugby union, (Roberts et al. 2010), and netball (Higgins et al. 2009). However, the demands imposed during such tests are likely to differ from the requirements experienced in basketball competition due to the differences in playing areas, movement patterns, and rules and regulations. As a result of the limited available data detailing the match activity demands of open-age male basketball competition, no test protocols have been developed that mimic the complete activity requirements of basketball match play. The construction of such a test might enable the replication of competition demands in a controlled environment, and may be useful in conditioning assessment, player selection, talent identification, and intervention testing (Roberts et al. 2010). Therefore, the development of a match-specific basketball simulation
test based on the activity requirements of competition may benefit the body of knowledge surrounding the sport.

To date, only separate anaerobic- and aerobic-based tests (Carvalho et al. 2011; Castagna et al. 2009, 2010; Delextrat & Cohen, 2008) have been used to assess basketball-related fitness. Previously, Carvalho et al. (2011) supported a basketball-specific repeat-sprint protocol as a valid instrument to assess anaerobic capacity in male basketball players. In addition, the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) has been frequently used as a fitness assessment tool for basketball players (Ben Abdelkrim et al. 2010a; Castagna et al. 2009, 2008b) and has been reported to display adequate validity in assessing aerobic fitness within basketball players (Castagna et al. 2008b). While both repeat-sprint tests and the Yo-Yo IR1 have been shown to validly evaluate important components of fitness related to basketball performance, they do not replicate the complete activity demands of basketball match play (Ben Abdelkrim et al. 2007; McInnes et al. 1995). Furthermore, given previous suggestions that basketball performance relies extensively upon various metabolic pathways (McInnes et al. 1995), a test that validly assesses anaerobic and aerobic basketball-related fitness in combination may prove advantageous for basketball players, coaches, and support staff. As such, the development of a basketball-specific test that simulates the activity demands of competition and assesses multiple components of basketball-related fitness is warranted.

Thus, the purpose of this study was to develop a reliable and valid basketball field test that replicates the activity requirements of elite open-age male basketball match play.
5.2 METHODS

5.2.1 Participants

Fifteen Australian male participants were recruited for this study. Participants were competing within state- (n = 6; age: 22.8 ± 6.9 yr; stature: 189.2 ± 8.4 cm; body mass: 84.6 ± 12.8 kg; body fat: 15.1 ± 3.3%) and regional-level basketball competitions (n = 9; 26.0 ± 3.8 yr; 185.9 ± 8.3 cm; 92.6 ± 8.9 kg; 23.2 ± 6.4%). All participants were of various on-court playing positions. The state-level players were completing ~6 h basketball training and participating in a maximum of two competitive matches (4 x 12-min quarters) per week during the study. The training schedule for state-level players consisted of three 2-h sessions. Two of these sessions involved ~40 min of conditioning drills and ~80 min of match practice activity, while the third session targeted tactical- and skill-based drills. The regional basketball players were physically active but not completing any structured basketball training across the present research. Further, all regional players were participating in one structured competitive match per week, consisting of 4 x 10-min quarters. Both the state and regional competitions were played in conjunction across a ~5-month period. All testing was completed across the mid-point of the playing season to ensure development of suitable match fitness within participants. Prior to testing, participants were screened for any contraindications to participate and voluntarily gave informed consent. All research procedures were granted prior approval by the CQUniversity Human Research Ethics Committee.

5.2.2 Study Design

Participants were required to complete 3-4 testing sessions. All participants were instructed to maintain consistent dietary and sleeping patterns for 48 h prior to each session and to refrain from strenuous activity for 24 h before each session. Further, each participant was instructed to drink ~500 ml of water an hour prior to testing to ensure they were in a euhydrated state upon arrival for each testing session. All testing occasions were conducted on two separate indoor regulation International Basketball Federation (FIBA) basketball courts, and were within similar environmental conditions (22.6 ± 1.2 °C; 63.1 ± 10.2%);
763.0 ± 1.7 mmHg). Each participant was tested at the same time of day upon each visit to control for circadian fluctuations. Further, all testing was conducted only in the presence of the research team, with standardised verbal encouragement given across each test to control participant arousal levels. Prior to all performance-based testing sessions, participants underwent a 15-min standardised warm-up consisting of low-intensity jogging, whole-body dynamic and static stretches, and brief bouts of high-intensity running. It was anticipated that training effects were unlikely to occur during the study from testing exposure given the conditioning levels of the participants and the brief stimuli of the test trials (Glaister et al. 2009).

During the first testing session, each participant was weighed using electronic scales (Tanita Corporation, Tokyo, Japan) and stature was measured using a portable stadiometer (Blaydon, Sydney, Australia). Body composition was assessed by a trained anthropometrist (Coefficient of Variation (CV) = 3.5%) from a nine-site skinfold profile (biceps, triceps, subscapular, abdomen, iliac crest, supraspinale, mid-axilla, front thigh, and medial calf) using Harpenden skinfold callipers (John Bull British Indicators, St. Albans, United Kingdom) and entering the data into Lifesize™ software (Human Kinetics, Lower Mitcham, Australia) (Norton and Olds, 1996). Following anthropometric measurement, all participants were familiarised with the repeat-sprint test, Yo-Yo IR1 and Basketball Exercise Simulation Test (BEST) through explanation of the test protocols. Participants then walked through both tests until familiar, and then ran through the protocols at varied speeds until competent in performance (Williams et al. 2009).

The second testing session was conducted 7 days following the initial session. All participants completed a repeat-sprint protocol consisting of 10 consecutive maximal sprints across the length of the court (10 x 28 m). Test performance was measured as the time taken to complete all sprints. Previously, similar protocols (12 x 20 m) have been used to assess repeat-sprint performance in basketball players (Meckel, Gottlieb, & Eliakim, 2009). Following adequate recovery (~30 min), each participant completed a Yo-Yo IR1 using previously described methodology (Krstrup et al. 2003). Total distance (m) covered
(excluding recovery activity) during the test was recorded as the primary performance measure (Castagna et al. 2008b). Participants then underwent further familiarisation of the BEST protocol after sufficiently recovering (~30 min) from the Yo-Yo IR1. Familiarisation involved participants running through the BEST at varied speeds, and then completing approximately 6-8 circuits at full intensity (Williams et al. 2009). At least 7 days following the Yo-Yo IR1, all participants completed a 12-min trial of the BEST during a third testing session. During the final testing occasion, at least 7 days following the previous session, nine (state: n = 4; regional: n = 5) participants completed an additional BEST trial.

Continuous measures of heart rate (HR) (b·min⁻¹) were recorded throughout all testing using Polar Team System HR monitors (Polar Electro, Oy, Kempele, Finland). Samples were taken every 5 s across each trial and recorded data were downloaded to a personal computer for analysis via Polar Precision Performance Software (Version 4.0, Polar Electro, Oy, Kempele, Finland) following each test.

5.2.3 The Basketball Exercise Simulation Test (BEST)

The BEST was developed using a circuit-based design, which was formulated using notational data from elite open-age Australian male basketball competition (see Studies One and Two). The maximal activity distance demands observed across one quarter of play were used in the BEST design. For ease of testing preparation, match distance data were implemented into the design of the BEST using court line-markings as indicators for activity and directional changes. Approximately 1725 m is travelled across a full 12-min BEST trial, including: LIA, 727 m (42%); HIA, 826 m (48%); and shuffling activity, 172 m (10%). These distances are comparable to maximal values reported during elite open-age male basketball competition (LIA: 40-44%; HIA: 47-51%; shuffling: 3-4%) (s) (see Studies One and Two) (see Figure 5.1).
Figure 5.1: The Basketball Exercise Simulation Test (BEST) circuit with movement distances using previous notational data based on the activity demands of elite open-age male basketball competition.
Each BEST circuit consisted of 30 s of activity, with the exact velocity of each activity being self-selected by participants. Circuits were generally completed in 20-25 s, therefore allowing 5-10 s of rest before the start of the next circuit. The circuits were performed continuously for 12 min to simulate the playing time of a live quarter of basketball competition, with a maximum of 24 circuits being completed. If participants were unable to complete a circuit in 30 s then no rest was given and participants were required to begin the next circuit immediately. In such instances, participants did not complete the required quantity of circuits (24) across testing unless adequate circuit timing was restored.

Instructions for the BEST were given to participants during the familiarisation process. The following activity categories were included:

1. Standing/walking: activity at no greater intensity than walking pace.
2. Jogging: activity at a moderate intensity, higher than walking pace but without urgency (~50% of maximal velocity).
3. Jogging: activity at a moderate intensity, higher than walking pace but without urgency (~50% of maximal velocity).
4. Jogging: activity at a moderate intensity, higher than walking pace but without urgency (~50% of maximal velocity).
5. Running: activity at a greater than moderate intensity, with effort and purpose but still below maximal exertion (~75% of maximal velocity).
7. Low shuffling: activity characterised by shuffling action of the feet within a defensive stance position, performed without urgency.
8. High shuffling: activity characterised by shuffling action of the feet within a defensive stance position, performed at maximal effort.

Prior to the sprinting component of each BEST circuit, participants were required to take a stationary position at the starting point to allow for accurate timing of sprint performance. Sprint and circuit times (s) were measured across each BEST circuit at the start and end points for the sprinting component, and prior to the final low-intensity phase, using a Swift
Speed Light Sports Timing System (Swift, Lismore, Australia) (see Figure 5.1). Performance measures taken across the BEST were sprint decrement (%), mean sprint and circuit times (s), and total distance covered (m). Sprint decrement was determined as the cumulative decline in sprint performance using mean times across each two-sprint effort, and calculated as \[((\text{total time/ideal time}) \times 100) – 100\]. Total time was determined as the sum of all two-sprint averages and ideal time was calculated as the fastest two-sprint average multiplied by the number of two-sprint efforts completed (Bishop et al. 2001).

5.2.4 Statistical Analyses

Means (± SD) were calculated for each dependent variable. Normality and homogeneity of variance for the present data were confirmed using the Kolmogorov-Smirnov Test and Levene’s Test for equality. To determine test-retest reliability of each BEST measure, Intra-class Correlation Coefficient (ICC) and Typical Error of Measurement (TEM) with 95% Confidence Intervals (CI) were calculated as per the methods of Hopkins (2000a). The CV with 95% CI was determined using the log-transformed raw data (Hopkins, 2000a). In addition, the smallest worthwhile change was calculated for each BEST measure as per previous methodology (Pyne, 2003). If the calculated TEM for a measure was less than, equal to, or greater than the determined smallest worthwhile change, a rating of ‘good’, ‘okay’, or ‘marginal’ was applied (Pyne, 2003). Criterion validity was determined by calculating the Pearson Product Moment Correlation Coefficient (r) between performance during the repeat-sprint test as well as the Yo-Yo IR1 and all BEST performance measures (Williams et al. 2009). The magnitude of correlation values was assessed using previous criteria: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; and 0.9-1.0, almost perfect (Hopkins, 2002). All statistical analyses were performed using the spreadsheet methods of Hopkins (2000b), Microsoft Excel™ (Microsoft, Redmond, Washington, USA), and Statistical Package for Social Sciences (SPSS) software (Version 17.0, SPSS Inc., Chicago, Illinois, USA). Statistical significance was accepted at \(p < 0.05\).
5.3 RESULTS

The mean (± SD) HR and performance data for all participants (n = 15) across the initial and retest (n = 9) BEST trials are displayed in Table 5.1. All reliability calculations are also presented in Table 5.1. Mean sprint (ICC = 0.99) and circuit time (ICC = 0.98), and sprint decrement (ICC = 0.93) displayed high (>0.90) reliability according to previous recommendations for physiological-based tests (Sassi et al. 2009). Poor (<0.80) ICC values were found for mean HR (ICC = 0.77) and total distance (ICC = 0.56) measures. Mean circuit time (1.4%) showed the lowest CV, followed by total distance (1.5%), mean sprint time (1.7%), mean HR (2.6%), and sprint decrement (14.6%). The smallest worthwhile change for sprint (0.03 s) and circuit time (0.53 s), as well as total distance (28.5 m) across the BEST were equal to or greater than the related TEM values, supporting the usefulness of these measures. The smallest worthwhile change calculations for mean HR (1.54 b·min⁻¹) and sprint decrement (1.09%) during the BEST were less than the associated TEM measures, rating the usefulness of these measures as marginal.

The mean performance time for all participants across the repeat-sprint protocol was 57.8 ± 5.3 s. Very large significant correlations were evident between repeat-sprint performance and mean sprint time (r = 0.916, p < 0.001), mean circuit time (r = 0.876, p < 0.001), sprint decrement (r = 0.812, p < 0.001), and total distance (r = -0.707, p = 0.003) across the BEST (see Figure 5.2). During the Yo-Yo IR1, all participants (n = 15) covered a mean distance of 970.7 ± 464.3 m. Very large significant correlations were evident between Yo-Yo IR1 distance and mean sprint time (r = -0.846, p < 0.001), sprint decrement (r = -0.838, p < 0.001), mean circuit time (r = -0.712, p = 0.003), and total distance covered (r = 0.710, p = 0.003) during the BEST (see Figure 5.3).
Table 5.1: Overall group data and test-retest measures of reliability for mean heart rate (HR), sprint decrement, mean sprint and circuit time, and total distance covered across a 12-minute trial of the Basketball Exercise Simulation Test (BEST).

<table>
<thead>
<tr>
<th>BEST Measure</th>
<th>Group (n = 15)</th>
<th>Trial 1 (n = 9)</th>
<th>Trial 2 (n = 9)</th>
<th>ICC</th>
<th>Absolute TEM (95% CI)</th>
<th>CV (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (b·min⁻¹)</td>
<td>175.9 ± 7.7</td>
<td>175.0 ± 9.0</td>
<td>177.2 ± 9.9</td>
<td>0.77</td>
<td>4.78 (3.23-9.15)</td>
<td>2.6% (1.8-5.1%)</td>
</tr>
<tr>
<td>Sprint decrement (%)</td>
<td>11.47 ± 5.44</td>
<td>11.74 ± 4.84</td>
<td>12.2 ± 5.16</td>
<td>0.93</td>
<td>1.41 (0.95-2.71)</td>
<td>14.6% (9.7-29.9%)</td>
</tr>
<tr>
<td>Mean sprint time (s)</td>
<td>1.53 ± 0.16</td>
<td>1.53 ± 0.18</td>
<td>1.54 ± 0.17</td>
<td>0.99</td>
<td>0.03 (0.02-0.05)</td>
<td>1.7% (1.1-3.2%)</td>
</tr>
<tr>
<td>Mean circuit time (s)</td>
<td>20.92 ± 2.64</td>
<td>20.96 ± 2.31</td>
<td>20.73 ± 2.24</td>
<td>0.98</td>
<td>0.30 (0.21-0.58)</td>
<td>1.4% (0.9-2.6%)</td>
</tr>
<tr>
<td>Total distance covered (m)</td>
<td>1639.5 ± 142.3</td>
<td>1718.4 ± 15.8</td>
<td>1703.4 ± 45.6</td>
<td>0.56</td>
<td>24.99 (16.88-47.88)</td>
<td>1.5% (1.0-2.8%)</td>
</tr>
</tbody>
</table>

ICC = Intra-class Correlation Coefficient; TEM = Typical Error of Measurement; CV = Coefficient of Variation; CI = Confidence Intervals.
Figure 5.2: Scatterplots showing the relationships between repeat-sprint time (s) and (A) sprint decrement (%), (B) mean sprint time (s), (C) mean circuit time (s), and (D) total distance covered (m) across the Basketball Exercise Simulation Test (BEST) (n = 15).

* $p < 0.01$; $^{*^*} p < 0.001$. 
Figure 5.3: Scatterplots showing the relationships between Yo-Yo IR1 distance (m) and (A) sprint decrement (%), (B) mean sprint time (s), (C) mean circuit time (s), and (D) total distance covered (m) across the Basketball Exercise Simulation Test (BEST) (n = 15).

* $p < 0.01$; $^{*} p \leq 0.001$. 
5.4 DISCUSSION

The present study describes the development of a field-based test replicating the activity demands of elite open-age male basketball competition. The BEST was observed to be both reliable and valid in assessing basketball-related anaerobic and aerobic fitness. Heart rate and performance measures of the BEST (sprint decrement, mean sprint and circuit time, and total distance) displayed high ICC, and/or low TEM and CV across test-retest trials. Furthermore, significant relationships were observed between each BEST measure and repeat-sprint performance as well as distance covered during the Yo-Yo IR1. Taken together, these results support the BEST as a reliable and valid match-specific test to assess basketball-related anaerobic and aerobic fitness.

Reliability has been frequently determined using test-retest methodologies in previous research examining repeat-sprint and circuit-based team sport simulation tests. Using this design, many researchers have calculated both ICC (Buchheit, 2008; Glaister et al. 2009; Sheppard et al. 2007; Tan et al. 2010; Zagatto et al. 2009) and TEM (Roberts et al. 2010; Sheppard et al. 2007; Tan et al. 2010; Williams et al. 2009) to determine the reproducibility of test measures. Previously, it has been suggested that ICC values >0.90 indicate high reliability, while values between 0.80-0.90 and <0.80 represent moderate and poor levels of reliability (Sassi et al. 2009). Moreover, it has been suggested that a physical test should display an ICC of at least 0.81 to be considered reliable for measures of sports performance (Hopkins, 2000a).

The present results revealed that mean sprint (ICC = 0.99) and circuit time (ICC = 0.98), and sprint decrement (ICC = 0.93) all displayed high ICC values, indicating a strong reliability for these measures. In contrast, poor reliability was observed for mean HR (ICC = 0.77) and total distance (ICC = 0.56) covered across the BEST. Previously, it has been suggested that when physical tests are conducted to discriminate between participants, the use of ICC as a measure of reliability is recommended (Impellizzeri & Marcora, 2009). As such, the ICC values from the present data suggest that mean sprint and circuit time, and sprint decrement all possess sufficient reliability to be used to differentiate basketball-related
fitness between individuals. Such basketball applications related to this function may include assessing players during team selection or comparing players from different competition levels. The poor reliability observed for total BEST distance may be due to the finite nature of this measure, with a maximum number of circuits (and total distance) able to be completed by participants.

Due to the limitations of using correlation analysis, such as the low sensitivity to changes in means between trials and the strong influence of inter-subject variation (Wragg et al. 2000), the calculation of TEM can provide a more comprehensive analysis of test reliability (Hopkins, 2000a). Within the present study, TEM was also used to assess the reliability of the BEST, as well as providing an indication of the random variation between test trials. Relative to TEM calculations, the additional determination of the smallest worthwhile change for each BEST measure provided insight into the practical usefulness of the BEST (Spencer et al. 2004). The present results indicate that the smallest worthwhile change for mean sprint and circuit time, and total distance taken across the BEST were greater than the related TEM values, and thus able to detect real changes in performance. Further, calculation of CV allowed comparison of reliability between measures and tests irrespective of units and scales used. As such, it has been proposed that measures displaying a CV of <5% have high reliability, and a CV of 10% is the upper limit of acceptance for reproducibility of a test (Atkinson et al. 1999). The present CV values suggest that most measures (mean HR, sprint and circuit time, and total distance) taken from the BEST possess high reliability (CV <5%). The only parameter with a CV >10% was sprint decrement (14.6%), though this is comparable to similar measures taken from other team sport simulation tests (Spencer et al. 2006).

Previously, fatigue measures such as declines in sprint performance and movement times have been reported to display poor reliability in many team sport simulation tests (Glaister et al. 2009; Sheppard et al. 2007; Spencer et al. 2006; Tan et al. 2010). Similar reliability values for fatigue measures to those observed in this study (CV = 14.6%, 95% CI = 9.7-29.9%) have been reported for a repeat-sprint field hockey simulation test (CV = 14.9%, 95%
CI = 10.8-31.3%) (Spencer et al. 2006). Furthermore, poorer levels of reliability have been observed for fatigue measures within other simulations for water polo (CV = 27.2%, 95% CI = 20.1-42.9%) (Tan et al. 2010), repeat-sprint sports (CV = 38.7%, 95% CI = 30.9-51.7%) (Glaister et al. 2009), and volleyball (CV = 82.3%) (Sheppard et al. 2007). These findings suggest that fatigue measures within team sport simulations may inherently be less reliable than other performance measures, and therefore should be used with discretion during performance analysis. It should also be mentioned, that the use of CV has been suggested to be most useful when tests are aimed at evaluating changes in responses with time (Impellizzeri & Marcora, 2009). Thus, the BEST measures displaying strong CV values (mean sprint and circuit time, and total distance) may be useful when assessing basketball fitness throughout the playing season or determining changes in player conditioning across training plans.

While the presented reliability calculations provide useful data concerning the reliability of the BEST, the use of generalised acceptance limits to rate findings as ‘good’ or ‘poor’ may promote erroneous conclusions. It has been suggested that determining the influence of measurement error on sample size estimation for test-retest ICC calculations can ascertain an acceptable level of reliability (Atkinson & Nevill, 2008). While these calculations were not provided within the present study, the smallest worthwhile change was determined for each BEST measure. Provision of smallest worthwhile change values may provide the critical level of error needed to determine if test scores are likely to be real and not simply due to testing error and typical variation (Pyne, 2003). As such, the practical relevance of this measure should be acknowledged when interpreting the present findings.

In addition to reliability measures, criterion validity of the BEST was determined in the present study through correlation analysis with repeat-sprint and Yo-Yo IR1 performance. To date, there appears to be no single test to holistically assess basketball-related fitness. However, individual tests have been reported to validly measure separate fitness components thought to contribute to basketball performance. Previously, repeat-sprint test protocols similar to the one used in the present study, have been observed to validly assess
anaerobic fitness in basketball players (Carvalho et al. 2011). Furthermore, the Yo-Yo IR1 has been reported to possess adequate reliability and a strong relationship ($r = 0.77, p < 0.001$) with aerobic capacity in basketball players (Castagna et al. 2008b). Thus, the use of these tests within the present study provides insight into the validity of the BEST in assessing elements of basketball-related fitness. The present data showed significant relationships between each BEST performance measure and repeat-sprint performance time, as well as Yo-Yo IR1 distance. As a result, the BEST might be suggested to be a valid test for the combined assessment of basketball-related anaerobic and aerobic fitness.

Further comparison between HR responses across the BEST with those reported during elite basketball competition can provide support to the external validity of the BEST. Within the present study, the mean HR during the BEST was $176 \pm 8 \text{ b\textperiodcentered min}^{-1} (90 \pm 3 \%HR_{\text{max}})$, which is similar to the HR responses previously reported for elite male basketball competition ($151-171 \pm 14 \text{ b\textperiodcentered min}^{-1}$ or $80-94 \%HR_{\text{max}}$) (Ben Abdelkrim et al. 2010a, 2010b, 2007; McInnes et al. 1995; Montgomery et al. 2010; Narazaki et al. 2009; Vaquera Jimenez et al. 2008). These data suggest that the cardiovascular strain of the BEST replicates that placed on players during actual matches. However, to comprehensively determine the external validity of the BEST, direct comparisons should be made with physiological and activity measures gathered during competitive matches within the same sample of participants.

Within the present study, a number of limitations were identified. Firstly, the present results are only representative of performance during the BEST within the included cohort. Thus, these data are unlikely to be representative of BEST performance within other basketball participants, including female players, participants of different ages, and national-level players. Secondly, the present research investigated a 12-min trial of the BEST as a representation of one quarter of play. Ideally, the reliability and validity of longer bouts of the BEST with rest periods to represent inter-quarter breaks could be calculated in order to assess basketball-related fitness over greater exercise durations indicative of actual match play. Finally, the performance of isometric contractions during static activity across basketball competition has been suggested to heighten the physiological stress placed upon
players (Ben Abdelkrim et al. 2007). However, due to the difficulties associated with incorporating these activities into the design of field-based tests, the BEST did not include any static actions specific to basketball competition.

5.5 CONCLUSION
In conclusion, the BEST is a field-based test that replicates the activity demands of current elite open-age male basketball competition. The test was observed to be a reliable and valid assessment tool for measuring basketball-related anaerobic and aerobic fitness. Mean sprint time taken during the BEST seemed to possess the greatest reliability and criterion validity in combination, and the limitations of the other measures should be considered when using them to assess basketball players.

5.6 PRACTICAL APPLICATIONS
The development of the BEST provides the first known field-based circuit test that specifically replicates the activity demands of elite open-age male basketball competition. The present data demonstrate that the BEST is a reliable and valid test for basketball players that can be used by coaches and support staff to assess basketball-related fitness within a controlled environment. Given its specificity to competition, the BEST may be used for player selection in precisely identifying individuals with adequate fitness capacities to cope with match play demands. Furthermore, due to the difficulties associated with measuring the effects of interventions during actual competition, the BEST could also be used in applied research studies to determine such outcomes.
Chapter 6

The construct and longitudinal validity of the Basketball Exercise Simulation Test (BEST)

Accepted for publication:

6.0 ABSTRACT

The purpose of this study was to assess the construct and longitudinal validity of the Basketball Exercise Simulation Test (BEST). State- (n = 10; age: 22.7 ± 6.1 yr; stature: 189.6 ± 9.5 cm; body mass: 86.5 ± 18.7 kg; body fat: 14.7 ± 3.5%) and regional-level (n = 10; 26.6 ± 4.0 yr; 185.9 ± 7.9 cm; 92.6 ± 8.4 kg; 23.8 ± 6.3%) Australian male basketball players volunteered for the study. Following familiarisation, each participant completed a repeat-sprint test, Yo-Yo Intermittent Recovery Test (Yo-Yo IR1), and Basketball Exercise Simulation Test (BEST) trial midway through the competitive season. Eight participants (state: n = 4; regional: n = 4) completed an additional repeat-sprint test, Yo-Yo IR1, and BEST trial within 7 days of the end of the playing season, 8 weeks following the initial testing phase. Performance measures from the BEST included sprint decrement (%), mean sprint and circuit time (s), and total distance covered (m). Construct validity was calculated using Student’s unpaired t-tests to identify statistically significant differences in repeat-sprint, Yo-Yo IR1, and BEST performance between playing levels. Longitudinal validity was determined by calculating the relationship between changes (%) in repeat-sprint as well as Yo-Yo IR1 performance and BEST performance across the season. State players performed significantly better across the repeat-sprint protocol (54.4 ± 8.3 s vs. 63.1 ± 21.5 s, p < 0.001), Yo-Yo IR1 (1283 ± 362 m vs. 636 ± 297 m, p = 0.001), and BEST (sprint decrement: 8.54 ± 0.15% vs. 15.38 ± 0.27%, p = 0.003; sprint time: 1.45 ± 0.01 s vs. 1.65 ± 0.03 s, p = 0.006; circuit time: 18.98 ± 1.79 s vs. 22.72 ± 2.01 s, p < 0.001) compared with regional players. For the group as a whole, a significant very large relationship was evident between changes in Yo-Yo IR1 performance and BEST sprint decrement (r = -0.815, p = 0.014) across the season. Moreover, non-significant large-very large correlations were observed between longitudinal changes in repeat-sprint performance and BEST sprint decrement (r = 0.581), and Yo-Yo IR1 performance and BEST circuit time (r = -0.705). In conclusion, the BEST displayed both construct and longitudinal validity within basketball players and provides a novel field test to assess basketball-related anaerobic and aerobic fitness in combination.

Key words: field test; simulation; intermittent performance.
6.1 INTRODUCTION

The activity requirements of basketball competition have received increased research attention across recent years (Ben Abdelkrim et al. 2010, 2009, 2010b, 2007; Janeira & Maia, 1998; Narazaki et al. 2009; Tessitore et al. 2006). However, much of the existing literature has described the activity demands of male basketball players during pre-season/practice matches (McInnes et al. 1995; Narazaki et al. 2006; Tessitore et al. 2009), in age-restricted populations (Ben Abdelkrim et al. 2010a, 2010b, 2007; Tessitore et al. 2009), or using non-specific movement categories (Bishop & Wright, 2006; Narazaki et al. 2009; Tessitore et al. 2006). Consequently, objective match activity data for elite open-age male players are limited (see Studies One and Two). From the available evidence, basketball competition can be described as highly intermittent, with sustained contributions from both glycolytic and oxidative metabolic pathways (Ben Abdelkrim et al. 2007; McInnes et al. 1995). As such, performance tests assessing basketball-specific fitness should account for these match requirements within their design.

The recent provision of activity data for open-age male basketball competition (see Studies One and Two) has facilitated the development of the first known field-based test specific to the activity demands of basketball match play, the Basketball Exercise Simulation Test (BEST) (see Study Three). The test-retest reliability of most performance measures taken from the BEST have been deemed acceptable (Intra-class Correlation Coefficient (ICC) = 0.93-0.98; Coefficient of Variation (CV) = 1.4-2.6%), with only total distance (ICC = 0.56) and sprint decrement (CV = 14.6%) displaying poor reliability. Further, the criterion validity of the BEST was supported with significant relationships ($r = \pm 0.69-0.92$) evident between test measures and repeat-sprint time as well as Yo-Yo IR1 distance.

Historically, basketball-specific fitness has been assessed using field tests based on skill-oriented performance (Barfield et al. 2007) or separate elements of player fitness (Carvalho et al. 2011; Castagna et al. 2009, 2008b, 2010; Delextrat & Cohen, 2008). While the validity of these tests in measuring individual fitness capacities within basketball players has been supported, their specificity to actual basketball competition might be questioned. The
unique intermittent demands and extensive contribution of moderate- and high-intensity activity and shuffling movements recently observed within open-age male basketball competition (see Studies One and Two), strengthen the suggestion that existing tests may not assess complete basketball-related fitness. In contrast, the recently developed BEST directly replicates the intermittent movement intensities and distances of activities performed in current elite Australian male basketball matches and has been supported as a valid tool for the combined assessment of basketball-related anaerobic and aerobic fitness (see Study Three).

It has previously been suggested that improvements in training quality have the greatest influence on increasing sport performance, and that the development of sport-specific simulation tests allows training adaptations to be most precisely assessed (Müller et al. 2000). However, prior to a simulation test being implemented, the validity related to its intended functions should be determined (Impellizzeri & Marcora, 2009). Firstly, if the aim of a test is to evaluate athlete performance, then the test should be validated against a criterion measure or test specific to the sport for which it is based (Impellizzeri & Marcora, 2009). As discussed, this “criterion validity” (Wilkinson et al. 2009b) has previously been supported for the BEST (see Study Three).

Secondly, if a test is used to select athletes, then it should be able to differentiate performance between separate playing levels (Impellizzeri & Marcora, 2009). This “construct validity” (Wilkinson et al. 2009b) has been frequently determined in many performance tests specific to sports such as squash (Wilkinson et al. 2009b), rugby league (Serpell et al. 2010), soccer (Gabbett, 2010), volleyball (Sheppard et al. 2007), and water polo (Mujika et al. 2006).

Finally, a test that is utilised to assess performance changes over time should be correlated against changes in a criterion performance measure or test over a specified period (Impellizzeri & Marcora, 2009). While no definitive criterion test has been identified for the assessment of basketball fitness, repeat-sprint protocols and the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) have been reported as valid tests for the separate assessment of
anaerobic and aerobic capacity in basketball players (Carvalho et al. 2011; Castagna et al. 2008b). Considering that the BEST is a match-specific test aimed at assessing anaerobic and aerobic basketball fitness in combination, longitudinal validity of this test may be determined using repeat-sprint and Yo-Yo IR1 protocols as criterion measures.

Therefore, for the BEST to be used validly as an evaluative assessment tool within basketball, it must demonstrate both construct and longitudinal validity. Thus, the purpose of the present study was to determine both the construct and longitudinal validity of the BEST.

6.2 METHODS

6.2.1 Experimental Approach to the Problem

This study builds on the previously reported reliability and criterion validity of the BEST (see Study Three) by determining the construct and longitudinal validity of this test. These measures have not been provided for any previously developed basketball-related fitness tests (Carvalho et al. 2011; Castagna et al. 2009, 2008b, 2010). Between- and within-subjects experimental designs were used in the present study to determine both the construct and longitudinal validity of the BEST. Similar to Serpell et al. (2010), construct validity was determined by comparing BEST results between high- (state) and low-performance playing groups (regional). Furthermore, participants were required to complete a trial of the BEST at the middle and end of the competitive playing season to assess longitudinal validity. Changes in performance between these trials were correlated against changes in performance on criterion tests for anaerobic and aerobic fitness in basketball players using similar methodology to Krustrup and Bangsbo (2001). Previously, low sample sizes have been frequently used to assess both the construct (n = 16-20) and longitudinal validity (n = 8) of sports performance tests (Gabbett, 2010; Krustrup & Bangsbo, 2001; Sheppard et al. 2007; Wilkinson et al. 2009a, 2009b).
6.2.2 Participants

Twenty male basketball players volunteered to participate within the present study. Participants were competing within state- (n = 10; age: 22.7 ± 6.1 yr; stature: 189.6 ± 9.5 cm; body mass: 86.5 ± 18.7 kg; body fat: 14.7 ± 3.5%), and regional-level basketball competitions (n = 10; 26.6 ± 4.0 yr; 185.9 ± 7.9 cm; 92.6 ± 8.4 kg; 23.8 ± 6.3%). Prior to participation, all state-level players had completed a 12-week pre-season conditioning program consisting of a combined training plan of agility, plyometric, anaerobic, and endurance components. For the duration of this investigation, the state-level players were participating in ~6 h of basketball-specific training per week, which consisted of ~160 min of practice match activity, ~80 min of on-court conditioning exercises, ~60 min of tactical development, and ~60 min of skill-based practice. All state players were also participating in a maximum of two competitive matches (4 x 12-min quarters) per week throughout the study. The regional players were physically active but not completing any structured basketball training across the present research. All regional players were participating in one structured competitive match per week, configured as 4 x 10-min quarters. The competitive seasons for both cohorts were played in conjunction. Further, all participants occupied various on-court playing positions.

Participants were instructed to maintain consistent dietary and sleeping patterns for 48 h prior to each session and to refrain from strenuous activity for 24 h before each session. Further, participants were instructed to drink ~500 ml of water an hour before each testing occasion to ensure they arrived in a euhydrated state. Prior to testing, all participants were screened for any medical contraindications for participation and gave voluntary informed consent. All research procedures were approved by the CQUniversity Human Research Ethics Committee prior to study commencement.
6.2.3 Procedures

All testing sessions were performed across two similar indoor venues on regulation International Basketball Federation (FIBA) hardwood basketball courts (23.6 ± 2.2 °C; 57.2 ± 11.4 %; 761.5 ± 2.6 mmHg). Time of testing was controlled during each visit for all participants to control for circadian fluctuations. Further, all testing was conducted only in the presence of the researchers, with standardised verbal encouragement given to participants across each test to control arousal levels.

The initial testing phase consisted of three sessions, which were conducted 8 weeks into each competition to ensure participants were of suitable match fitness prior to testing. The subsequent testing phase involved two sessions and was conducted 8 weeks following the completion of the initial testing. The subsequent sessions were scheduled during the final week of the competitive season and 1 week following season completion (see Figure 6.1).

Prior to all performance-based testing sessions, participants underwent a 15-min standardised warm-up consisting of low-intensity jogging, whole-body dynamic and static stretches, and brief bouts of high-intensity running. At the first testing session, all participants underwent a physical assessment including measurement of body mass on electronic scales (Tanita Corporation, Tokyo, Japan) and stature using a portable stadiometer (Blaydon, Sydney, Australia). Participants also had a nine-site skinfold measurement (biceps, triceps, subscapular, abdomen, iliac crest, supraspinale, mid-axilla, front thigh, and medial calf) taken by a trained anthropometrist (Coefficient of Variation (CV) = 3.5%) to determine body composition as per Norton and Olds (1996). Skinfold thickness for each site was measured using Harpenden skinfold callipers (John Bull British Indicators, St. Albans, United Kingdom) and entered into Lifesize™ software (Human Kinetics, Lower Mitcham, Australia). In addition, the repeat-sprint, Yo-Yo IR1, and BEST protocols were explained to all participants during this session. Participants were then walked through all tests until they were comfortable with the protocols, and then ran through them at varied speeds until they were familiar with the movement patterns.
Figure 6.1: Schematic representation of the testing schedule used to assess the construct and longitudinal validity of the Basketball Exercise Simulation Test (BEST).
The second testing session was conducted at least 7 days later with all participants completing a repeat-sprint protocol consisting of 10 consecutive maximal sprints across the length of the basketball court (10 x 28 m). Time taken to complete all sprints was taken as the performance measure for the repeat-sprint test. Similar basketball repeat-sprint protocols have been shown to validly assess anaerobic capacity in basketball players (Carvalho et al. 2011). Following adequate recovery (~30 min), each participant undertook a Yo-Yo IR1 following previously described procedures (Krustrup et al. 2003). Total distance (m) covered (excluding recovery activity) during the test was taken as the performance measure (Castagna et al. 2008b). Previously, the Yo-Yo IR1 has been reported to display acceptable reliability (CV = 4.9%) (Krustrup et al. 2003) and validly assess aerobic fitness within basketball players (Castagna et al. 2008b). Further familiarisation of the BEST was conducted after sufficient recovery (~30 min) from the Yo-Yo IR1 and consisted of participants running through the test at varied speeds and then completing 6-8 circuits at testing intensity.

During the third testing session at least 7 days later, all participants completed a 12-min BEST trial. The design of the BEST was formulated using reported notational data for elite open-age Australian male basketball competition (see Studies One and Two). Approximately 1725 m is travelled across a 12-min BEST trial when all circuits are completed, including 727 m of LIA (42%), 826 m of HIA (48%), and 172 m of shuffling activity (10%). These distances are comparable to maximal values reported during elite male basketball competition (LIA: 40-44%; HIA: 47-51%; shuffling: 3-4%) (see Studies One and Two). The circuit design of the BEST is shown in Figure 6.2.
Figure 6.2: Layout of the Basketball Exercise Simulation Test (BEST).
Each BEST circuit consisted of 30 s of activity at a self-selected velocity. Circuits were generally completed in 20-25 s, therefore allowing 5-10 s of rest before the start of the next circuit. The circuits were performed continuously for 12 min to simulate the playing time of a live quarter of basketball competition, with a maximum of 24 circuits being completed. If circuits were not completed in 30 s then no rest was given and participants were required to begin the next circuit immediately. In these circumstances, participants did not complete the required quantity of circuits (24) across testing unless regular circuit timing was restored. Prior to performing the sprinting bout during each BEST circuit, participants were required to take a stationary position at the starting point to permit accurate timing of sprint performance.

The following descriptions of activities performed across the BEST were given to participants during familiarisation, similar to definitions previous described (McInnes et al. 1995):

1. Standing/walking: activity at no greater intensity than walking pace.
2. Jogging: activity at a moderate intensity, higher than walking pace but without urgency (~50% of maximal velocity).
3. Running: activity at a greater than moderate intensity, with effort and purpose but still below maximal exertion (~75% of maximal velocity).
4. Sprinting: all-out effort at maximal intensity.
5. Low shuffling: activity characterised by shuffling action of the feet within a defensive stance position, performed without urgency.
6. High shuffling: activity characterised by shuffling action of the feet within a defensive stance position, performed at maximal effort.
7. Jumping: countermovement maximal effort jump initiated off both legs.

Eight participants (state: n = 4; regional: n = 4) (23.6 ± 5.0 yr; 187.4 ± 7.2 cm; 88.8 ± 10.6 kg; 21.2 ± 6.9%) completed two follow-up testing sessions, 8 weeks after the initial testing phase. During these sessions, participants completed a further repeat-sprint test, Yo-Yo IR1, and 12-min BEST trial at least 7 days apart. The present testing schedule was expected to
elicited minor training effects considering the physical condition of the participants and the brief nature of the test trials (Glaister et al. 2009).

Heart rate (HR) (b·min⁻¹) was continually recorded throughout all testing using Polar Team System HR monitors (Polar Electro, Oy, Kempele, Finland) at 5 s intervals. Data were downloaded to a personal computer for analysis via Polar Precision Performance Software (Version 4.0, Polar Electro, Oy, Kempele, Finland). Maximal HR was determined as the highest reading taken during the Yo-Yo IR1. All timing of the BEST circuits was measured using a Swift Speed Light Sports Timing System (Swift, Lismore, Australia). Mean sprint and circuit times (s), total distance covered (m), and sprint decrement (%) were taken as performance measures during the BEST and have been frequently utilised within other team sport simulation tests (Bishop et al. 2001; Roberts et al. 2010; Williams et al. 2009). Sprint decrement was calculated as $[((\text{total time}/\text{ideal time}) \times 100) – 100]$ (Bishop et al. 2001). Total time was determined as the sum of all two-sprint averages and ideal time was calculated as the fastest two-sprint average multiplied by the number of two-sprint efforts completed (Bishop et al. 2001). This calculation of sprint decrement has been reported to be the most reliable and valid method to assess fatigue during repeat-sprint tests (Glaister, Howatson, Pattison & McInnes, 2008).

6.2.4 Statistical Analyses

Means (± SD) were calculated for all measures. To assess normality and homogeneity of variance, the Kolmogorov-Smirnov Test and Levene’s Test for equality were conducted and supported the present data. To determine construct validity, Student’s unpaired t-tests were used to identify any differences in repeat-sprint, Yo-Yo IR1, and BEST performance (sprint decrement, mean sprint and circuit time, and total distance) between the state and regional playing groups. Cohen’s $d$ was also calculated to determine the effect size (ES) between groups and was interpreted using the following criteria: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and >2.0, very large (Hopkins, 2002). Longitudinal validity was determined by calculating the Pearson Product Moment Correlation Coefficient ($r$) between changes (%) in repeat-sprint time, Yo-Yo IR1 distances, and all BEST performance.
measures across the playing season. Correlation strength was assessed using previous criteria: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; and 0.9-1.0, almost perfect (Hopkins, 2002). All statistical analyses were performed using the spreadsheet methods of Hopkins (2000b), Microsoft Excel™ (Microsoft, Redmond, Washington, USA), and Statistical Package for Social Sciences (SPSS) software (Version 17.0, SPSS Inc., Chicago, Illinois, USA). Statistical significance was accepted at \( p < 0.05 \).

6.3 RESULTS

The mean (± SD) Yo-Yo IR1 and BEST performance data for the state (n = 10) and regional players (n = 10) are presented in Table 6.1. State-level players (n = 10) performed significantly better during the repeat-sprint test (54.4 ± 8.3 s vs. 63.1 ± 21.5 s, \( p < 0.001, \text{ES} = 0.5 \)) and Yo-Yo IR1 (1282.9 ± 361.9 m vs. 635.6 ± 296.9 m, \( p = 0.001, \text{ES} = 2.0 \)) compared with regional-level players. Further, state players demonstrated significantly faster mean times for the sprint (1.45 ± 0.01 vs. 1.65 ± 0.03 s, \( p = 0.006, \text{ES} = 8.9 \)) and circuit measures (18.98 ± 1.79 s vs. 22.72 ± 2.01 s, \( p < 0.001, \text{ES} = 2.0 \)) across the BEST. Lastly, the state players demonstrated significantly less fatigue (8.54 ± 0.15% vs. 15.38 ± 0.27%, \( p = 0.003, \text{ES} = 31.3 \)) than regional players during the BEST.

Over the duration of the study, non-significant trivial-small changes were evident in all performance measures for the eight participants longitudinally assessed (state: n = 4; regional: n = 4). Non-significant improvements (1.8 ± 12.7%, \text{ES} = 0.03) in Yo-Yo IR1 distance, as well as BEST sprint decrement (2.0 ± 16.1%, \text{ES} = 0.06), mean circuit time (1.8 ± 3.3%, \text{ES} = 0.06), and total distance covered (0.9 ± 2.3%, \text{ES} = 0.58) were observed across the 8-week period. However, BEST mean sprint time (0.2 ± 5.0%, \text{ES} = 0.12) and repeat-sprint performance (3.0 ± 4.9%, \text{ES} = 0.31) showed non-significant small-trivial decrements. Pearson Correlation analysis revealed a very large negative relationship (\( r = -0.815, p = 0.014 \)) between changes in Yo-Yo IR1 distance and BEST sprint decrement across the season (see Figure 6.4). While non-significant, large-very large correlations were also evident between longitudinal changes in repeat-sprint performance and BEST sprint decrement (\( r = 0.581 \)) (see Figure 6.3), and Yo-Yo IR1 distance and BEST circuit time (\( r = -0.705 \)) (see Figure 6.4).
Table 6.1: The heart rate (HR) and performance data (mean ± SD) for Australian male state- (n = 10) and regional-level (n = 10) basketball players during the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) and Basketball Exercise Simulation Test (BEST), and for players longitudinally assessed (n = 8) at mid-season and end-season.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Playing cohort</th>
<th>Magnitude of differences</th>
<th>Longitudinal assessment</th>
<th>Magnitude of differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>State</td>
<td>Regional</td>
<td>Effect size</td>
</tr>
<tr>
<td>Yo-Yo IR1 distance (m)</td>
<td>1282.9 ± 361.9*</td>
<td>635.6 ± 296.9</td>
<td>1.96</td>
<td>Large</td>
</tr>
<tr>
<td>Repeat-sprint time (s)</td>
<td>54.4 ± 8.3*</td>
<td>63.1 ± 21.5</td>
<td>0.53</td>
<td>Small</td>
</tr>
</tbody>
</table>

**BEST Measures**

| Measures                       | State | Regional | Effect size | Rating | Mid-season | End-season | Effect size | Rating |
| HR (b∙min⁻¹)                   | 178.8 ± 7.1 | 178.7 ± 11.0 | 0.01       | Trivial | 173.5 ± 8.7 | 176.1 ± 8.9 | 0.30       | Small   |
| %HRmax (%)                     | 92.4 ± 5.4  | 90.7 ± 3.8  | 0.36       | Small   | 88.3 ± 3.7 | 89.6 ± 3.3 | 0.37       | Small   |
| Sprint decrement (%)           | 8.54 ± 0.15* | 15.38 ± 0.27 | 31.32      | Very large | 13.20 ± 5.30 | 12.89 ± 5.49 | 0.06       | Trivial |
| Mean sprint time (s)           | 1.45 ± 0.01* | 1.65 ± 0.03 | 8.94       | Very large | 1.55 ± 0.18 | 1.54 ± 0.17 | 0.06       | Trivial |
| Mean circuit time (s)          | 18.98 ± 1.79* | 22.72 ± 2.01 | 1.97       | Large    | 21.24 ± 2.22 | 20.98 ± 1.96 | 0.12       | Trivial |
| Total distance (m)             | 1670.1 ± 115.9 | 1585.2 ± 152.4 | 0.63       | Moderate | 1709.6 ± 37.1 | 1725 ± 0 | 0.58       | Small   |

Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test; BEST = Basketball Exercise Simulation Test; %HRmax = Relative heart rate
* Significant (p < 0.01) difference between state and regional playing groups.
Figure 6.3: Scatterplots showing the relationships between changes (\%) in repeat-sprint time (s) and (A) sprint decrement (\%), (B) mean sprint time (s), (C) mean circuit time (s), and (D) total distance covered (m) during the Basketball Exercise Simulation Test (BEST) (n = 15) across the playing season. \*p < 0.05.
Figure 6.4: Scatterplots showing the relationships between changes (%) in Yo-Yo IR1 distance (m) and (A) sprint decrement (%), (B) mean sprint time (s), (C) mean circuit time (s), and (D) total distance covered (m) during the Basketball Exercise Simulation Test (BEST) (n = 15) across the playing season. *p < 0.05.
**6.4 DISCUSSION**

The present study aimed to determine both the construct and longitudinal validity of the BEST. The data demonstrate that the BEST is capable of detecting changes in basketball-related anaerobic and aerobic fitness between basketball players of different competition standards (state vs. regional), and assessing basketball-related fitness across a playing season. This builds on previous data which support the BEST as a reliable tool for assessing basketball-related fitness relative to anaerobic- and aerobic-based criterion tests (see Study Three).

The BEST is a circuit-based field test that has been constructed based upon the intermittent movement patterns experienced during elite open-age male basketball competition. To be used appropriately as a fitness test, the BEST should possess adequate criterion, construct, and longitudinal validity (Impellizzeri & Marcora, 2009). Previously, the criterion validity of the BEST has been reported to be acceptable, with sprint decrement, and mean sprint and circuit time measures displaying significant ($p < 0.001$) correlations with repeat-sprint and Yo-Yo IR1 performance (see Study Three). These findings suggest that the BEST is a suitable match-specific test to evaluate anaerobic and aerobic basketball fitness in combination when compared to generic criterion tests widely used in the sport. Further, the BEST provides an intermittent stimulus and movement types relevant to basketball competition that may give insight into physical limitations or weaknesses that are not assessed in generic field testing.

The present data demonstrate that the BEST also possesses both construct and longitudinal validity. This suggests that the BEST can both discriminate between the basketball-related anaerobic and aerobic fitness of players from different competition levels and evaluate changes in match-related sprint fatigue over time. The comparison of different competition levels has been frequently used to determine construct validity within many simulation tests for team sports such as rugby league (Serpell et al. 2010), soccer (Gabbett, 2010), volleyball (Sheppard et al. 2007), water polo (Mujika et al. 2006), and handball (Buchheit et al. 2010). The present study compared the BEST performance of state- and regional-level basketball
players to assess construct validity. The greater basketball-related fitness observed for the state players compared with the regional players, as evidenced by superior performance during the BEST, is likely due to the variations in training loads and match demands between these groups.

Throughout the present study, all state-level players were completing basketball-specific training and playing up to two competitive matches per week, while all regional players were not completing any structured basketball-specific training and only competing in one recreational match per week. Given the previously reported fitness benefits with basketball-specific training (Balciunas et al. 2006; Laplaud et al. 2004), and greater match demands for higher levels of basketball competition (Ben Abdelkrim et al. 2010a), the state players were likely to possess advanced basketball-specific conditioning compared with the regional players. Such competition level differences are also reflected in research reporting on the fitness attributes across different basketball playing standards (Ben Abdelkrim et al. 2010c; Delextrat & Cohen, 2008; Metaxas et al. 2009; Sallet et al. 2005).

Basketball players participating in higher levels of competition have been observed to possess greater VJ, 20 m sprint, and agility performance capabilities (Ben Abdelkrim et al. 2010c; Delextrat & Cohen, 2008), and larger anaerobic and aerobic capacities (Ben Abdelkrim et al. 2010c; Metaxas et al. 2009; Sallet et al. 2005) than players participating within lower competitions. Considering that each of these fitness components has been suggested to contribute to basketball performance (Ben Abdelkrim et al. 2007; McInnes et al. 1995), they may assist in explaining the lower sprint decrement, and shorter mean sprint and circuit times achieved during the BEST within the state players. As such, the BEST may provide a testing stimulus that presents data encompassing these performance characteristics specific to basketball match play, and remove the need to repeat generic field testing. Furthermore, strong correlations between sprint performance and repeated-sprint ability have been previously reported in team sport athletes (Pyne et al. 2008). Thus, the BEST provides data that discriminate on selected measures of physical fitness that have historically been of interest to sport science practitioners.
The present study observed no significant difference between groups for total distance (m) covered during the BEST. This is most likely due to the BEST having an upper-limit of performance, with a maximum number of circuits (and total distance) able to be completed by participants across the test. As such, once participants have attained an adequate level of fitness to complete the maximum BEST distance, the more sensitive measures of sprint decrement, and mean sprint and circuit times should be used to provide feedback on basketball fitness. Therefore, the validity of the BEST distance measure should be considered when interpreting test results. Overall, the BEST appears to be capable of discriminating between basketball playing levels through the reporting of several measures that are pertinent to match performance. Thus, the present data demonstrate that the BEST possesses adequate construct validity.

Longitudinal validity describes the ability of a test to assess performance changes over time by comparing changes in a criterion test to those in the test being examined (Impellizzeri & Marcora, 2009). The present study compared changes in repeat-sprint and Yo-Yo IR1 performance with changes in BEST performance across an 8-week period of the competitive playing season in basketball players. The significant negative relationship ($r = -0.815$, $p = 0.014$) between changes in Yo-Yo IR1 distance (m) and BEST sprint decrement (%) demonstrates that the BEST possesses acceptable longitudinal validity for the assessment of basketball-related aerobic fitness. Further, the non-significant large correlation ($r = 0.581$) observed between changes in repeat-sprint time and BEST sprint decrement adds support for the longitudinal validity of the BEST in the evaluation of basketball-related anaerobic fitness. Previous research has observed sprint decrement to possess the strongest construct and logical validity within fatigue measures for performance test protocols (Glaister et al. 2008). The current data provide the first known results for the longitudinal validity of this measure within sport-specific testing protocols. The present findings suggest that both the sprint decrement (%) and mean circuit time (s) may be the most valid performance measures to use when evaluating longitudinal changes in measures taken from the BEST.
While longitudinal validity is suggested to be essential in the development of performance tests, few existing studies examining sport-specific simulations have provided this measure (Krustrup & Bangsbo, 2001; Mujika et al. 2006). Previously, Krustrup and Bangsbo (2001) investigated the relationship between changes in Yo-Yo IR1 performance and high-intensity running during matches in top-class soccer referees following a 12-week intermittent training intervention. A strong correlation \((r = 0.77)\) between improvements in Yo-Yo IR1 performance and increases in high-intensity running during matches was observed, which supported the longitudinal validity of the Yo-Yo IR1 (Krustrup & Bangsbo, 2001). These observations also justify the use of the Yo-Yo IR1 to assess performance changes over time in the present study. More recently, Mujika et al. (2006) examined the changes in performance in the Water Polo Intermittent Shuttle Test over the course of a competitive season within junior elite water polo players. The test was observed to detect changes in match performance, although this was subjectively assessed and the test was not objectively correlated against a criterion test or measure.

Taken together, the current data demonstrate that the BEST has both acceptable construct and longitudinal validity. However, the interpretation of the results may be subject to a small number of limitations. Firstly, the current data represent test performance for state and regional male basketball players only, and do not attempt to report on populations outside of this such as females, juniors, and national-level players. However, similar playing groups have been utilised within previous validation research (Serpell et al. 2010). Secondly, the current study employed a small sample size when compared to more population-based research. However, the current sample size \((n = 8-20)\) is adequate given those previously reported for team sport field test validation studies \((n = 8-20)\) (Gabbett, 2010; Krustrup & Bangsbo, 2001; Sheppard et al. 2007; Wilkinson et al, 2009a, 2009b) and basketball-specific research \((n = 8-22)\) (Castagna et al. 2008b, 2010; Delextrat & Cohen, 2008). The small sample size did limit the analysis of the present data by not allowing the comparison of different playing positions within each competition level. Previously, backcourt (guards) and frontcourt (forwards and centres) basketball players have been reported to possess
different fitness capacities (Ben Abdelkrim et al. 2010c; Sallet et al. 2005) and experience varied demands across competition (Ben Abdelkrim et al. 2007; McInnes et al. 1995). As such, positional analysis during the BEST may provide greater insight into the validity of the test for various basketball playing positions. Finally, the present research observed trivial-small changes in fitness when validating the BEST across the playing season (~8 weeks). As such, to determine the responsiveness of the BEST to greater fitness adaptations, further longitudinal studies should examine the effects of varied training loads across longer durations on BEST performance.

6.5 CONCLUSION

In conclusion, the present results demonstrate that the BEST is a valid match-specific test that can both discriminate between playing levels and quantify longitudinal changes in basketball-related fitness. Moreover, the present data suggest that sprint decrement may be the most valid BEST measure as evidenced by the performance differences between different playing levels and large-very large relationships with repeat-sprint and Yo-Yo IR1 performance changes across the playing season for this parameter.

6.6 PRACTICAL APPLICATIONS

The BEST is the first sport-specific fitness test shown to be representative of the intermittent activity demands of open-age male basketball competition. The present study suggests that the BEST may be used to validly discriminate players on basketball-related anaerobic and aerobic fitness in combination, as well as assess changes in these characteristics over time. The discriminative ability of the BEST may enable it to be used by basketball coaching and conditioning staff as a practical assessment tool during player selection, return to play scenarios, and talent identification practices. Given that basketball competition has been suggested to impose unique physical demands upon players (Ben Abdelkrim et al. 2007; McInnes et al. 1995), the accurate identification and selection of players with superior fitness attributes specific to the sport may prove advantageous for coaching staff.
The observed longitudinal validity suggests that the BEST could be used to assess changes in basketball-related anaerobic and aerobic fitness within players over time. Considering basketball-related fitness characteristics have been reported to vary across phases of a competitive season (Hoffman et al. 1991), it may prove useful to use the BEST to monitor changes in anaerobic and aerobic parameters together across seasonal phases.
Chapter 7

Summary and Conclusions
7.0 SUMMARY

To date, limited scientific research has described and compared the current match activity demands of different basketball playing levels (Ben Abdelkrim et al. 2010a). Furthermore, no match activity data have been provided for Australian or open-age male basketball competition under the current rules of the sport. As a result, existing field and laboratory tests aimed at assessing basketball-related fitness are largely restricted to measuring skill-based activity or non-specific basketball fitness components. Thus, the main aims of the present thesis were to describe and compare the precise match activity demands of current elite and sub-elite open-age Australian male basketball competitions, and use these data to develop the first known reliable and valid basketball simulation test specific to elite match demands. These objectives were addressed within four sequential research studies.

Study One described the activity requirements of open-age Australian male basketball competition, and compared these demands between elite and sub-elite playing levels using video-based time-motion analysis (TMA). Activity frequencies, mean and total durations, and mean and total distances were determined for various activity categories. The results suggest that elite basketball players experienced more frequent changes in movement intensity and greater sustained activity demands than sub-elite players across matches. In contrast, sub-elite players performed more frequent bouts of explosive activity with longer recovery periods than elite players. Thus, the overall match activity demands imposed upon elite open-age Australian male basketball players appear greater than sub-elite competition.

Using data from Study One, Study Two examined the intra-match activity variation across playing quarters during elite and sub-elite open-age Australian male basketball competitions. Elite players experienced larger declines in high-intensity activity during latter match periods than sub-elite players. Furthermore, elite players competed at reduced dribbling and overall movement velocities during the later stages of matches compared with earlier periods of play. In contrast, greater increases in match stoppage durations were evident across matches for sub-elite players compared with elite players. These findings suggest that elite competition may involve greater ball control and reduced high-intensity court transitions.
during later match periods, whereas sub-elite competition may contain greater recovery opportunity to allow for increased maintenance of activity intensity across match quarters.

Study Three detailed the development of a reliable and valid test specific to the match activity demands of elite open-age male basketball competition. The Basketball Exercise Simulation Test (BEST) was developed using data gathered within Studies One and Two. Measures taken across the BEST included mean heart rate, sprint decrement, mean sprint and circuit time, and total distance covered. Test-retest reliability and criterion validity were calculated for the BEST. Very large Intra-class Correlation Coefficients (0.93-0.99) were observed for mean sprint and circuit time, and sprint decrement, while all BEST measures exhibited high Coefficients of Variation (CV) (<5%), except sprint decrement (CV = 14.6%). The BEST also displayed adequate criterion validity with significant correlations evident between mean sprint and circuit time, and sprint decrement during the BEST and repeat-sprint performance (r = 0.81-0.92), as well as Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) distance (r = -0.71-0.85). It was concluded that the BEST is reliable and valid in assessing basketball-related anaerobic and aerobic fitness.

Adding to the findings of Study Three, Study Four determined both the construct and longitudinal validity of the BEST. Construct validity was calculated through comparing repeat-sprint, Yo-Yo IR1, and BEST performance between state and regional basketball competition levels. Longitudinal validity was evaluated by correlating changes in both repeat-sprint and Yo-Yo IR1 performance with BEST performance across 8 weeks of a competitive season. Significant differences between state and regional basketball players were observed in repeat-sprint time (16%), Yo-Yo IR1 performance (102%), as well as sprint decrement (80%), and mean sprint (14%) and circuit time (14%) across the BEST. In addition, large-very large relationships were observed between changes in repeat-sprint time (r = 0.581), as well as Yo-Yo IR1 performance (r = -0.815), and BEST sprint decrement across the season. Thus the BEST was shown to demonstrate both construct and longitudinal validity as an instrument to assess basketball-related anaerobic and aerobic fitness.
7.1 CONCLUSIONS

The present thesis described the development of the BEST based on the activity demands of current open-age Australian male basketball competition. To date, a lack of available activity data exists for open-age male basketball competition, within Australia and internationally. As such, no known basketball simulation test specific to match activity demands has been developed. Therefore the present findings are original and provide a unique insight into the match activity requirements imposed upon elite and sub-elite open-age male basketball players. The following conclusions can be drawn from the thesis:

• Current open-age Australian male basketball competition elicits greater intermittent and sustained activity intensities, and reduced shuffling workloads than previously reported during male basketball competition.

• The activity demands of open-age Australian male basketball players vary with competition level. Specifically, elite competition requires greater intermittent workloads and more consistent effort at or above moderate movement intensities across matches than sub-elite competition. In contrast, sub-elite players experience more frequent maximal-intensity activity, with longer recovery durations than elite players. Furthermore, these competition level differences are evident irrespective of playing position (backcourt and frontcourt).

• The intra-match activity variation within open-age Australian male basketball competition also differs between playing levels. Elite players appear to experience greater decrements in activity intensity with match progression than sub-elite players. These discrepancies may be due to the varied roles of fatigue mechanisms, as well as tactical play and match constraints.

• The BEST is a reliable and valid match-specific field test for measuring basketball-related anaerobic and aerobic in combination. Various measures of the BEST possess acceptable criterion, construct, and longitudinal validity with sprint decrement observed as the most valid testing parameter.
7.2 PRACTICAL IMPLICATIONS

The present thesis has several practical implications, which are summarised in Figure 7.1 below.

**Figure 7.1**: The practical implications of the present thesis.
The match activity demands of open-age Australian male basketball players described in Studies One and Two offer a number of practical benefits to the sport of basketball:

- These results may allow more valid basketball conditioning programs to be developed that better replicate the physical loads placed on basketball players during competition. The reported activity data provide precise detail concerning the physical workloads and intensities encountered across current open-age Australian male basketball matches. The results suggest that intermittent and agility conditioning, as well as training consistently at moderate-high intensities may require greater consideration than previously thought. Further, the observed playing standard variations in match activity requirements indicate that fitness and performance capacities may differ between elite and sub-elite competitions. As such, the present results may permit the accurate development of improved conditioning programs for lower-level players.

- The present match activity data objectively illustrate differences in the match activity requirements of elite and sub-elite playing levels. These findings may assist in transitioning players to higher playing levels through facilitating the progress of developing players from lower competitions.

- Further, the playing level comparisons made in the present thesis may assist basketball talent identification practices, through the detection of fitness properties and performance capacities essential for elite competition. As such, players identified to possess fitness attributes indicative of elite match play may enter specialised basketball programs aimed at developing skill and tactical performance.

- Finally, the intra-match activity variations observed for open-age male players may assist basketball coaches and support staff in developing effective player management strategies. These data provide insight into the possible effects of fatigue responses, tactical play, and match constraints throughout basketball competition. As such, coaches may be able to implement strategies, such as player substitutions, time-outs, and team structures to maintain optimal performance with match progression.
Studies Three and Four describe the development, reliability, and validity of the BEST. The BEST has strong practical appeal considering that it can be used within normal basketball environments and it can be applied over varied durations. Furthermore, when manual timing devices are used in place of electronic timing gates, multiple players can be assessed simultaneously and minimal preparatory time and equipment are necessary. The present results supported the criterion, construct, and longitudinal validity of the BEST, which permit its application within a number of basketball-related areas:

- Similar to Studies One and Two, the BEST may be used to reliably and validly assess, monitor, and improve the basketball-related fitness of developing players. Such processes may prove useful in transitioning players to higher playing levels and identifying players with physical capacities suitable for elite competition.

- The BEST allows the assessment of basketball-related fitness while replicating the demands of elite open-age male basketball competition. Consequently, the BEST could be used to determine match-readiness through assessing the conditioning of players following pre-season training, across the competitive season, following injury rehabilitation, and across various training phases.

- With adequate construct validity, the BEST may be used during player selection processes. Given the heavy intermittent and sustained moderate-high intensity activity requirements observed during elite open-age male basketball competition, conditioning is likely to be a major determinant for successful performance. As such, coaches and conditioning staff may use the BEST to select players for team squads, when other areas of performance, such as skill and tactical intelligence are similar.

- The BEST enables basketball-related anaerobic and aerobic fitness to be measured within controlled environments and thus used within various applied research settings. This may include the evaluation of player responses to nutritional and training interventions or various ergogenic aids. Thus, the BEST may strengthen the current understanding of basketball match activity demands and be used to precisely assess the effects of various performance-enhancing strategies on basketball-related fitness.
The practical implications of the present thesis aim to improve basketball performance. Nevertheless, to maximise the effectiveness of the aforementioned practical applications, future research directions could be suggested.

### 7.3 FUTURE RESEARCH DIRECTIONS

Further research is needed to develop a definitive understanding of the match demands of basketball competition and for the development of simulation tests specific to a wider sample of basketball players. As such, a number of research directions may stem from the present thesis:

- Quantifying the basketball match activity demands of specific play phases (such as offense and defence), categorising activity intensity based on individual player capacities such as maximal sprint speed, identifying movement direction during activity analysis, and including isometric efforts may provide greater insight into the movement demands of basketball competition. Such data may facilitate the development of more advanced basketball conditioning plans. Furthermore, the use of technologies that may become available to allow accurate player tracking indoors (i.e. radio frequency tracking systems) may permit greater data acquisition within basketball TMA studies.

- Various competition factors are inherent within team sports, and are likely to influence the demands imposed upon players during competition. Future basketball TMA studies should account for these factors and include competition scheduling, playing venue, opposition ranking, and match score data when analysing the activity demands of basketball competition. This information may allow basketball coaches and support staff to implement more effective pre-match player preparation methods, management strategies during competition, and recovery practices following matches.
• Investigation of basketball match activity demands should be expanded to a wider variety of basketball populations. Given the reported differences in anthropometric and fitness characteristics, as well as competition responses between players of different ages, gender, and geographical regions, the match requirements of these players may vary (Apostolidis et al. 2003; Barfield et al. 2007; Ben Abdelkrim et al. 2010a, 2010b, 2007; Delextrat & Cohen, 2009; Lamonte et al. 1999; Matthew & Delextrat, 2009; Montgomery et al. 2010; Ostoic et al. 2006; Rodriguez-Alonso et al. 2003; Tessitore et al. 2006). Such data would provide a greater understanding of the activity demands within different basketball competitions, and permit the development of conditioning programs and simulation tests specific to these playing groups.

• Overall basketball performance is not dependent solely upon physical conditioning. It has been suggested that other factors such as skill level, tactical parameters, and cognitive function all influence performance (Angyan et al. 2003; Ben Abdelkrim et al. 2010a; Grehaigne & Godbout, 1995). Therefore, a basketball simulation test that includes these parameters as well as the physical requirements of match play, may allow more specific assessments of complete basketball performance within controlled settings.
Chapter 8

References


Appendix 1

Information and Informed Consent Documents
Dear Participant,

The purpose of this study is to examine the match activity demands of elite and sub-elite basketball competitions. The following pages will provide you with information outlining the background of the present study, the procedures that will be undertaken, and list any possible risks associated with this study. The present study is being administrated through the School of Medical and Applied Sciences, CQUniversity.

INTRODUCTION

The sport of basketball involves regular periods of low-intensity activity interspersed with bouts of high-intensity activity. Previous researchers have described the activity demands of basketball competition using time-motion analysis techniques, whereby player activity is captured through video recordings and further analysed with the use of computer software. Despite the availability of this precise technology, no existing research has utilised it to examine the current demands placed on open-age male basketball players during competition anywhere in the world.

Further to this lack of available data on basketball match activity demands, no researchers have endeavoured to examine differences between open-age male competition levels. Such information would prove invaluable in designing the most effective conditioning programs for basketball players and transitioning players to higher playing levels. Therefore, the current study aims to provide the first data on the current activity demands placed upon open-age male basketball players during competition, and compare these demands between levels of play.

METHODS

During the present study, all participants will be required to partake in an initial health screening and fitness assessment session. This session will likely coincide with a training/fitness session organised by your coach.
Health and Fitness Assessment
Through the use of a questionnaire, the investigators will screen all participants for any medical conditions that may prevent them from partaking in the intense fitness exercises. If you exhibit any medical conditions you will be asked to visit a general practitioner.

During this session you will have a number of simple physical measures taken to assess your fitness level. Such assessment will involve the measurement of:

- **Body composition**: in the form of body mass, stature, skinfolds, girth, and bone breadth measurements.
- **Maximal aerobic capacity**: through a maximal multi-stage “beep” test. This test will involve participants exercising maximally, therefore a sufficient warm-up protocol will be conducted prior to the test:
  - Participants are required to walk/jog/run a distance of 20 metres for each increment of the “beep” test, conducted through the use of an audio CD.
  - Participants must reach the required distance (20 metres) before each increment is deemed complete, which is indicated through the sound of a “beep”.
  - Increments of the test gradually increase in speed.
  - Once a participant cannot attain the designated distance for two successive increments, they are deemed to have reached their respective maximum effort.
  - Participants are able to withdraw from the test at any time should they feel any discomfort or they are unable to complete the increment.
- **Vertical jump height**: participants are required to perform three attempts each for two different types of maximal jumps:
  - Standing jump: participants jump from standing on two feet, with no arm swing.
  - Three stride jump: participants take three steps before performing the jump.
- **Agility**: a simple timed run, whereby participants are required to cover a short distance (20-30 metres) with multiple changes in direction.

Match Activity
Across multiple competitive matches, all player activity on the court will be video-recorded and reanalysed to determine the activity demands of basketball competition.

ANALYSIS
A written report will be sent to each participant concerning their individual and team results. A verbal explanation of the results will also be provided after the completion of testing to inform how they relate to your training, conditioning and performance. It is up to each participant to then provide their own results to their coach.

RISKS
During the fitness testing session you will be asked to perform maximal intensity exercise which may cause some discomfort. You will have been screened to ensure that you do not have any existing medical conditions that may indicate that you should not undertake maximal exercise. If health risk factors are found to exist which contraindicate exercise participation, then you will be referred to a medical doctor to obtain approval to participate or be excluded from this study.
ANONYMITY
The confidentiality of the results of this study is assured. Under no circumstances will your name appear in publications associated with this research. Your results will be provided to you both in written and verbal form with nobody else being given copies unless you request it. Hard and electronic copies of your results shall be stored in a locked filing cabinet and saved on a password-protected computer.

CONSENT
By reading and complying with this form you confirm that you understand and acknowledge the procedures and risks involved in participating in the current project and give consent to perform numerous tests during the initial health and fitness testing session, and be videotaped during matches.

ENQUIRIES
Any enquiries or concerns regarding the nature or conduct of the proposed research can be directed to the principal or supervising researcher whose contact details are presented at the beginning of this document.

FREEDOM TO WITHDRAW
You are free to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form you are not waiving your legal claims, rights or remedies.

Please contact CQU University Office of Research should there be any additional concerns:
Phone: 07 4923 2607
E-mail: ethics@cqu.edu.au
Address: Level 4, Building 351, CQU University, Rockhampton Qld 4702
INFORMED CONSENT

NAME: ________________________________________________________________

SIGNATURE: __________________________ DATE: ____________________________

CONTACT DETAILS

Address: __________________________________________________________________________

Email: __________________________________________________________________________

Phone: (H):_______________________ (M): ______________________________

SPECIAL CONSIDERATIONS: 

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

GUARDIAN INFORMED CONSENT

(For participants under the age of 18 years)

I have read and understood all of the information contained within the “participant informed consent document” and give permission for ____________________________________________________________ to participate in the basketball research project. In signing this consent form I am not waiving my legal claims, rights or remedies.

NAME OF LEGAL GUARDIAN: ________________________________________________

SIGNATURE: __________________________ DATE: ____________________________

CONTACT DETAILS:

Address: ______________________________________________________________________

Email: ______________________________________________________________________

Phone: (H):_______________________ (M): ______________________________

INVESTIGATOR’S SIGNATURE: __________________________ DATE: ____________________________
INFORMATION SHEET AND CONSENT FORM

The Basketball Exercise Simulation Test: A match-specific physical fitness test for basketball players

Dear Participant,

The purpose of this study is to develop a field-based fitness test specific to the activity demands of elite basketball competition. This document will provide you with information outlining the background of this study, the procedures that will be undertaken and list any possible risks. The present study is being administered through the School of Medical and Applied Sciences, CQUniversity.

INTRODUCTION

The development of sport-specific tests allows the fitness of players to be measured and monitored. To date, no field-based fitness tests have been developed specific to basketball. This is largely due to the limited amount of research available describing the precise activity demands of basketball competition.

The first study of this project used video-based analysis to describe the exact activity demands experienced by both elite (national level) and sub-elite (state level) Australian players during competition. This is the first data of its kind to be provided within basketball. Furthermore, it was observed that basketball requires athletes to perform vigorous intermittent activity, meaning that it involves regular periods of low- to moderate-intensity activity interspersed with bouts of high-intensity activity. Therefore, any fitness test developed for basketball must incorporate varied movement intensities in its design.

Additionally, a newly developed fitness test must function in a highly reliable and valid manner. To be reliable, a test must produce consistent measures when conducted within a specified period. The validity of a test refers to its ability to measure what it claims to measure. This involves the test being compared against a comparable measure, being able to discriminate between performances of different competition levels, and being sensitive enough to identify changes in performance across periods of time.
PURPOSE OF THE STUDY
The purposes of the proposed research are to:

• Develop a simulation test (Basketball Exercise Simulation Test (BEST)) based on the specific activity requirements of elite basketball competition.
• Determine the reliability of the BEST through test-retest comparisons.
• Determine the validity of the BEST through comparisons with a repeat-sprint test and the Yo-Yo Intermittent Recovery Test, between players of different competition levels, and across the season.

SIGNIFICANCE OF THE STUDY
The present study is the first to develop a field-based fitness test specific to the overall activity demands of basketball competition. Such a test will assist coaches, players, and support staff in measuring the basketball-related anaerobic and aerobic fitness of players. This will prove beneficial in basketball through assessing the effectiveness of conditioning programs, transitioning players to higher competition levels, and testing athletic aids that are aimed at improving player performance.

METHODS
During the present study, all participants will be required to partake in a health and fitness assessment, and performance of the Basketball Exercise Simulation Test (BEST):

Health and Fitness Assessment
Through the use of the attached questionnaire, all participants will be screened for any medical conditions that may prevent them from partaking in the project. If you exhibit any medical conditions you will be asked to visit a general practitioner.

Prior to performing the BEST, you will have a number of simple physical measures taken to assess your current fitness level. Such assessment will involve the measurement of:

• **Body composition:** in the form of body mass, stature, skinfolds, girth, and bone breadth measurements.
• **Repeat sprint test:** a timed run of 10 consecutive full-court sprints.
• **Yo-Yo Intermittent Recovery Test:** a maximal fitness test to assess maximal intermittent capacity.
  ➢ Each participant begins on or behind the middle line, and begins running 20 m when instructed by the CD.
  ➢ Each participant returns to the starting point when signalled by the recorded beep.
  ➢ There is an active recovery period between every (out and back) shuttle, during which the participant can walk or jog around the other cone and return to the starting point.
  ➢ A warning is given when each participant does not complete a successful shuttle in the allocated time, and they are removed the next time they do not complete a shuttle.

The Basketball Exercise Simulation Test (BEST)
The BEST will consist of a half-court circuit layout with each segment of the circuit requiring a specific movement type (stand/walk, jog, run, sprint, low-intensity shuffling, high-intensity shuffling, and jumping). Each participant will be given 30 seconds to complete each circuit and will be required to complete 24 circuits (12 minutes of activity) per test. If a participant finishes the circuit prior to the allotted 30 seconds, then the remaining time before the commencement of the next circuit will be a recovery period. If a participant takes longer than 30 seconds to complete a circuit, they will be required to commence the next circuit immediately after coming to a complete stop, without a
recovery period and continue the test for the entire 12 minutes. The time taken to complete each sprinting bout and each circuit will be measured across the test. The percentage (%) decrement in sprint time will provide an additional performance measures across the BEST.

**REQUIREMENTS**
Your physical measures will be gathered first during an initial testing session. During this time, you will be required to complete a repeated sprint test and Yo-Yo Intermittent Recovery Test. Following this you will be required to complete the BEST on two separate occasions within 7 days of each other. Finally, to assess the validity of the BEST, you will be required to complete another repeated sprint test, Yo-Yo Intermittent Recovery Test and BEST towards the end of the season at a later date.

**ANALYSIS**
A written report will be sent to each participant concerning their individual results and overall group results. A verbal explanation of the results will also be provided after the completion of testing to inform you how they relate to your training, conditioning and performance.

**RISKS**
During testing you will be asked to perform maximal intensity exercise which may cause some discomfort. You will have been screened to ensure that you do not have any existing medical conditions that may indicate that you should not undertake maximal exercise. If health risk factors are found to exist, then you may be referred to a medical doctor to obtain approval for participation.

**ANONYMITY**
The confidentiality of the results of this study is assured. Under no circumstances will your name appear in publications associated with this research. Your results will be provided to you both in written and verbal form with no one else being given copies unless you request it. Hard and electronic copies of your results shall be stored in a locked filing cabinet and saved on a password-protected computer.

**CONSENT**
By reading and complying with this form you confirm that you understand and acknowledge the procedures and risks involved in participating in the preset project and give consent to continue participation.

**FREEDOM TO WITHDRAW**
You are free to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form you are not waiving your legal claims, rights or remedies.

---

Please contact CQUUniversity Office of Research should there be any additional concerns:
Phone: 07 4923 2607
E-mail: ethics@cqu.edu.au
Address: Level 4, Building 351, CQUiversity, Rockhampton Qld 4702
INFORMED CONSENT

NAME: ____________________________________________

SIGNATURE: ___________________________ DATE: ______________________

CONTACT DETAILS

Address: ____________________________________________

Email: ____________________________________________

Phone: (H): ___________________________ (M): ______________________

SPECIAL CONSIDERATIONS:
_____________________________________________________
_____________________________________________________
_____________________________________________________

GUARDIAN INFORMED CONSENT

(For participants under the age of 18 years)

I have read and understood all of the information contained within the “participant informed consent document” and give permission for ____________________________________________ to participate in the basketball research project. In signing this consent form I am not waiving my legal claims, rights or remedies.

NAME OF LEGAL GUARDIAN: ____________________________________________

SIGNATURE: ___________________________ DATE: ______________________

CONTACT DETAILS:

Address: ____________________________________________

Email: ____________________________________________

Phone: (H): ___________________________ (M): ______________________

INVESTIGATOR’S SIGNATURE: ___________________________ DATE: ______________________
Appendix 2

Revised Physical Activity Readiness Questionnaire (rPARQ)
Revised Physical Activity Readiness Questionnaire (rPARQ)

Name: ___________________________________ Date: __________

Date of birth: ________________________________ Sex: M F (Circle one)

1. When was the last time you had a physical examination? ______________________________

2. Has any member of your family been treated for or suspected to have any of the following conditions? Please identify their relationship to you (e.g. mother, father, etc).
   a. Diabetes                        YES NO _____________
   b. Heart disease/attack    YES NO _____________
   c. Stroke                             YES NO _____________
   d. High blood pressure        YES NO _____________
   e. Peripheral Artery Disease   YES NO _____________

3. Do you Smoke? YES NO
   If no, have you quit within the last 6 months YES NO

4. Do you know your blood fat content? YES NO
   Please list:  Cholesterol: _____________mmol∙L⁻¹
                 VLDL: _____________mmol∙L⁻¹
                 LDL: _____________mmol∙L⁻¹
                 HDL: _____________mmol∙L⁻¹

5. Have you ever been told you have abnormal blood pressure? YES NO
   Was it high or low (please circle) HIGH LOW

6. Are you currently taking any medication? If so what are they? (Please list)
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

7. If you are allergic to any foods, medications or other substances, please list them here.
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

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8. If you have been told that you have any chronic disease or serious illness, please name them here.


9. Have you been hospitalised in the past three (3) years? Please give details.


10. During the past twelve (12) months;

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Has a physician prescribed any medication for you?</td>
<td>☐</td>
</tr>
<tr>
<td>Has your weight fluctuated more than a few kilograms?</td>
<td>☐</td>
</tr>
<tr>
<td>If yes, did you control this weight change by diet and/or exercise?</td>
<td>☐</td>
</tr>
<tr>
<td>Have you experienced faintness, light headiness or blackouts?</td>
<td>☐</td>
</tr>
<tr>
<td>Have you experienced unusual heartbeats?</td>
<td>☐</td>
</tr>
<tr>
<td>Have you felt as though your heart was racing for no apparent reason?</td>
<td>☐</td>
</tr>
</tbody>
</table>

11. At present, do you:

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience shortness or loss of breath when walking?</td>
<td>☐</td>
</tr>
<tr>
<td>Experience sudden tingling or numbness in limbs or face?</td>
<td>☐</td>
</tr>
<tr>
<td>Experience swelling in your feet or ankles?</td>
<td>☐</td>
</tr>
<tr>
<td>Experience pains or cramps in your legs?</td>
<td>☐</td>
</tr>
<tr>
<td>Experience any pain or discomfort in your chest?</td>
<td>☐</td>
</tr>
<tr>
<td>Experience any pressure or heaviness in your chest?</td>
<td>☐</td>
</tr>
<tr>
<td>Suffer from diabetes?</td>
<td>☐</td>
</tr>
<tr>
<td>If yes, how is it controlled (circle)?</td>
<td></td>
</tr>
<tr>
<td>Dietary means</td>
<td>Insulin injection</td>
</tr>
</tbody>
</table>

12. Have you ever had asthma? YES NO

13. How often would you characterise your stress levels as being high?

<table>
<thead>
<tr>
<th>Occasionally</th>
<th>Frequently</th>
<th>Constantly</th>
</tr>
</thead>
</table>
14. Tick the appropriate box indicating whether or not you have previous suffered from any of the following conditions?

<table>
<thead>
<tr>
<th>Condition</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Myocardial Infarction</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Arteriosclerosis</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Heart Disease</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Heart Block</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. Coronary Thrombosis</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6. Rheumatic Heart Complication</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7. Heart Attack</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>8. Aneurism</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9. Coronary Occlusion</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>10. Angina</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>11. Heart Failure</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>12. Heart Murmur</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>13. Neuromuscular Disorder</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>14. Peripheral Artery Disease</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>15. Pulmonary Embolism</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>16. Deep Vein Thrombosis</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>17. Compartment Syndrome</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>18. Oedema</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

SCREENING CHECKLIST:

- ☐ Apparently healthy individual
- ☐ Medical examination required
- ☐ Sub-maximal test required
- ☐ Diagnostic testing required
- ☐ Inadequate information given
- ☐ Exclusion from study

Participant: ___________________________ Date: ________________

Investigator: __________________________ Date: ________________
Appendix 3

Institutional Ethics Approval
MEMORANDUM
From the Office of Research

17 April 2008

Mr Aaron Scanlan
Health & Human Performance
Building 77
CQU Rockhampton Campus

Dear Mr Scanlan

HUMAN RESEARCH ETHICS COMMITTEE ETHICAL APPROVAL PROJECT:
H08/02-008. THE DEVELOPMENT OF A BASKETBALL SIMULATION TEST BASED
ON THE CURRENT PHYSIOLOGICAL AND ACTIVITY DEMANDS IMPOSED UPON
SUB-ELITE AND ELITE BASKETBALL PLAYERS DURING COMPETITIONS

The Human Research Ethics Committee is an approved institutional ethics committee
constituted in accord with guidelines formulated by the National Health and Medical
Research Council (NHMRC) and governed by policies and procedures consistent with
principles as contained in publications such as the joint Universities Australia and NHMRC
Australian Code for the Responsible Conduct of Research.

On 16 April 2008, the Human Research Ethics Committee of the Central Queensland
University acknowledged compliance with the conditions placed on ethics approval for the
research project, The development of a basketball simulation test based on the current
physiological and activity demands imposed upon sub-elite and elite basketball players
during competitions Project number H08/02-008

The period of ethics approval will be from 16 April 2008 to 16 September 2009. The
approval number is H08/02-008; please quote this number in all dealings with the Committee.

The standard conditions of approval for this research project are that:

(a) you conduct the research project strictly in accordance with the proposal
submitted and granted ethics approval, including any amendments required to be
made to the proposal by the Human Research Ethics Committee;

(b) you report immediately anything which may warrant review of ethics approval of
the project, including:
   (i) serious or unexpected adverse effects on participants;
   (ii) proposed changes in the protocol;
   (iii) unforeseen events that might affect continued ethical acceptability of the
project;
   (A written report detailing the adverse occurrence or unforeseen event must be submitted
to the Committee Chair within one working day after the event.)

(c) you provide the Human Research Ethics Committee with a written “Annual
Report” by no later than 28 February each calendar year and “Final Report” by
no later than one (1) month after the approval expiry date;

Page 1 of 2
(A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)

(d) if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;

(e) you make submission to the Human Research Ethics Committee for approval of any proposed variations or modifications to the approved project before making any such changes;

(f) you comply with each and all of the above conditions of approval and any additional conditions or any modification of conditions which may be made subsequently by the Human Research Ethics Committee;

(g) you advise the Human Research Ethics Committee (email: ethics@cqu.edu.au) immediately if any complaints are made, or expressions of concern are raised, in relation to the project.

Please note that failure to comply with the conditions of approval and the National Statement on Ethical Conduct in Human Research may result in withdrawal of approval for the project.

You are required to advise the Secretary in writing within five (5) working days if this project does not proceed for any reason. In the event that you require an extension of ethics approval for this project, please make written application in advance of the end-date of this approval. The research cannot continue beyond the end date of approval unless the Committee has granted an extension of ethics approval. Extensions of approval cannot be granted retrospectively. Should you need an extension but not apply for this before the end-date of the approval then a full new application for approval must be submitted to the Secretary for the Committee to consider.

The Human Research Ethics Committee wishes to support researchers in achieving positive research outcomes. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Secretary, Sue Evans or myself.

Yours sincerely,

[Signature]

Dr Lorna Moxham
Chair, Human Research Ethics Committee

Cc: A/Prof Peter Reesburn
Dr Ben Dascombe
Project File

Application Category: A
Appendix 4

Time-Motion Analysis Reliability Data
## ICC Calculations

<table>
<thead>
<tr>
<th>Movement category</th>
<th>Intra-tester Reliability</th>
<th>Inter-tester Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite</td>
<td>Sub</td>
</tr>
<tr>
<td>Frequency</td>
<td>Mean Duration</td>
<td>Mean Distance</td>
</tr>
<tr>
<td>Walk</td>
<td>0.97</td>
<td>0.99</td>
</tr>
<tr>
<td>Jog</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Run</td>
<td>0.92</td>
<td>0.90</td>
</tr>
<tr>
<td>Sprint</td>
<td>0.97</td>
<td>0.99</td>
</tr>
<tr>
<td>Low Shuffle</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>High Shuffle</td>
<td>0.96</td>
<td>1.00</td>
</tr>
<tr>
<td>Dribble</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Jump</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>Upper-body</td>
<td>0.99</td>
<td>0.97</td>
</tr>
</tbody>
</table>

213
<table>
<thead>
<tr>
<th>Activity Category</th>
<th>Frequency</th>
<th>Mean Duration (s)</th>
<th>Mean Distance (m)</th>
<th>Total Duration (s)</th>
<th>Total Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite</td>
<td>Sub</td>
<td>Elite</td>
<td>Sub</td>
<td>Elite</td>
</tr>
<tr>
<td>Walk</td>
<td>4.4 (2.3-27.5)</td>
<td>1.2 (0.7-4.3)</td>
<td>0.01 (0.01-0.40)</td>
<td>0.08 (0.04-0.29)</td>
<td>0.03 (0.02-0.11)</td>
</tr>
<tr>
<td>Jog</td>
<td>5.6 (2.9-35.0)</td>
<td>0.5 (0.2-2.9)</td>
<td>0.06 (0.03-0.22)</td>
<td>0.04 (0.02-0.14)</td>
<td>0.09 (0.05-0.32)</td>
</tr>
<tr>
<td>Run</td>
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## TEM (95% CI) for Inter-tester Calculations

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### CV (95% CI) for Intra-tester Reliability

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## CV (95% CI) for Inter-tester Calculations

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