The Performance and Physiological Demands of Basketball
Competition and Training.

Paul Grant Montgomery
BAppSc, BAppSc (Hons)

School of Physiotherapy and Exercise Science
Griffith Health
Griffith University

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Abstract

The demands and nature of basketball competition involve repeat high intensity efforts within a game, and during multi-game national and international tournaments. These demands require that the fitness and conditioning attributes of basketball players are well developed to negate the limiting aspects of cumulative fatigue. This fatigue may be attributed to several physical, physiological and psychological factors. Muscle soreness and damage combined with neuromuscular fatigue and metabolite accumulation might also limit muscular performance. Energy substrate depletion and central nervous system fatigue are also causative factors that limit skill execution, the intensity of exercise and basketball performance. To date there has been no quantification and description of the combined physical and physiological demands of basketball training and competition, nor the performance outcomes and fatigue associated with tournament style play.

The current understanding of aerobic conditioning, with particular reference to the oxygen uptake of basketball players is limited. However the development of heart rate telemetry systems that predict oxygen uptake and energy expenditure provides a practical means of determining the demands of training and competition. Initially, oxygen uptake (VO\textsubscript{2}) and energy expenditure predictions by the Suunto™ heart rate system were validated against a first principles gas analysis system. Well-trained male (n=10, age 29.8 ± 4.3 y, VO\textsubscript{2} 65.9 ± 9.7 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; mean ± SD) and female (n=7, 25.6 ± 3.6 y, 57.0 ± 4.2 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) runners completed a two stage incremental running test to establish criterion sub-maximal and maximal oxygen uptake values. Metabolic cart values were used as the criterion measure of VO\textsubscript{2} and energy expenditure (kJ) and compared with the predicted values from the Suunto™ heart rate monitoring system. The three levels of software analysis for the Suunto™ system were evaluated: basic personal information (BI), BI + measured maximal heart rate (BIhr), and BIhr + measured VO\textsubscript{2} (BIhr+v). Comparisons were analysed using linear regression to determine the standard error of the estimate (SEE): eight subjects repeated the trial within seven days to determine reliability (typical error). Although VO\textsubscript{2} (~1.5%) and energy expenditure (~3%) estimations were reliable, the Suunto™ system at the basic heart rate-based level of analysis underestimated VO\textsubscript{2} and energy expenditure by ~6% and ~13% respectively. However, the estimation can be improved when maximal heart rate and VO\textsubscript{2} values are added to the software analysis. The results provide confidence that heart rate monitoring is a useful means of determining the physical demands of basketball training and competition.

In study two, a three day tournament was devised to evaluate the fatigue associated with this style of competition, and the effectiveness of recovery strategies on physical performance. Male players (n=29, 19.1 ± 2.1 y, 1.84 ± 0.34 m, 88.5 ± 14.7 kg) were randomly assigned to one of three recovery strategies: control (n=9), cold water immersion (11°C, 5 x 1 minute (CWI), n=10) and full leg compression garments (18mmHg, ~18 hrs, n=10). Effects of the recovery strategies on pre-post tournament performance tests were expressed as % ± SD of the change score. Changes and differences were standardized for accumulated game time, assessed against the smallest worthwhile change for each test, and reported qualitatively. Accumulated fatigue was evident over the tournament with small - moderate impairments in several performance tests. Sprint and agility performance decreased by 0.7% ± 1.3 and 2.0% ± 1.9 respectively. Vertical jump also decreased substantially after the first day for all treatments, and remained suppressed at post-tournament. The use of
Cold water immersion was substantially better in maintaining speed with only a 0.5% ± 1.4 reduction in 20 m sprint time after three days, compared with a 3.2% ± 1.6 reduction after wearing compression garments. Cold-water immersion and compression showed similar substantial benefits in maintaining line-drill performance over the tournament, whereas the control treatment elicited a small increase. Sit & reach flexibility decreased for all groups, however cold-water immersion had the smallest reduction in flexibility. The effect of tournament style play induces impairments of up to 3.2% in tests of physical performance; however these impairments can be offset by up to 1.8% with the use of recovery interventions. Additionally, the use of cold-water immersion appears to promote better restoration of these physical performance measures than carbohydrate+stretching routines and compression garments with the accumulation of game time.

The decrements in performance measures may be associated with muscle damage and soreness associated with the high eccentric loads experienced during basketball play. In study 3, the time course of muscle damage markers and inflammatory cytokines during tournament play was investigated. The effect of emerging recovery strategies on any post-game increases of these biomarkers was compared with traditional refuelling and stretching routines. Male players (19.1 ± 2.1 y; 1.91 ± 0.09 m; 88 ± 15 kg, mean ± SD) competed in a three day tournament playing one game each day. Players were assigned to one of three recovery treatments: carbohydrate+stretching, (n=9; CON), cold-water immersion at 11°C for 5×1 min, (n=10; CWI); full-leg compression at 18 mmHg for ~18 h, (n=10; COMP). Players received their treatment after each game on three consecutive days. Venous blood samples were collected pre-tournament and at 10 minutes, 6 h and 24 h after each game and assayed for concentrations of muscle damage markers fatty-acid binding protein (FABP), creatine kinase (CK) and myoglobin (Mb), and the cytokines interleukin-6 (IL-6) and interleukin-10 (IL-10). Inferences were based on log-transformed concentrations. Post-game increases in damage markers were very large for FABP and Mb, and small for CK after all treatments, with small differences between treatments. There were moderate to large post-game increases in IL-6, while increases in IL-10 were moderate for CWI, and large after COMP and CON. Small decreases in IL-6 and IL-10 were observed under CWI compared to COMP and CON, with no difference between treatments over the tournament. There was no substantial benefit from any recovery treatment at post-game, but there were small - moderate differences between CWI and the COMP or CON treatments for the post tournament measures compared to pre tournament. Tournament play elicits moderate elevations in muscle damage markers suggesting disruption of myocyte membranes in well-trained players. The increase in cytokines may be related to an associated inflammatory response, but also to other physiological considerations. However, the cumulative use of cold-water immersion does appear to minimise concentrations of muscle damage markers after repeated competition, and provide and acute analgesic effect.

Basketball coaches have expressed concern that court coverage ability of emerging players is decreasing on an annual basis, potentially due to large in-season training and competition loads, or that development programs were not adequately preparing players. To determine gender differences, positional differences, and patterns of change in court coverage assessed by the basketball line-drill test, male (n=93; age 16.8 ± 1.1 y, (mean ± standard deviation) and female (n=95; age 16.5 ± 1.0 y) basketball players undertook 516 line-drill tests over a 5 year period. The line drill test is a repeat effort test of court coverage routinely used in training, and standardised testing. Log-transformed performance times were analysed using a mixed model that included quadratic within-subject fixed effects for time in the season and time in the
program. Changes and differences were standardised for interpretation of magnitudes. Mean performance times were ~28.0 s for males and ~30 s for females. The mean pattern of change in performance within a season differed substantially between genders and playing positions: male guards and female centres showed moderate to very large improvements mid-season of 1.1% and 3.5% respectively (90% confidence limits ±2.1% and ±3.0%), while female guards and male forwards showed large to very large decrements of -1.6% (±2.6%) and -2.4% (±2.0%). Over three years, males improved performance across all three playing positions by 1.4% (±1.3%) and females by 2.9% (±1.4%). Males improved performance by 0.2% (±0.5%) per year, while females decreased by 0.6% (±0.4%) per year. Coaches can be assured that the differing patterns of performance change presumably reflect variations in training and competition loads, with short-term fluctuations in performance being managed to promote longer-term improvements.

The final study characterised and compared the physical and physiological responses during basketball practice and competition. Existing studies have employed elementary time-motion analyses, but not investigated in detail the physical demands based on a ‘whole body’ approach. Whole body demands were assessed using triaxial accelerometry, with physiological demands determined by the heart rate telemetry technology validated in study 1. Male basketball players (n=11; 19.1 ± 2.1 y, 1.91 ± 0.09 m, 87.9 ± 15.1 kg; mean ± SD) completed a prescribed series of offensive and defensive training drills, half court 5on5 scrimmage play, and competitive games. Heart rate, VO₂ and triaxial accelerometer data (physical demand) were normalised for individual athlete participation time. Data were log-transformed and differences between drills and games standardized for interpretation of magnitudes and reported with the effect size (ES) statistic. There was no substantial difference between offensive and defensive drills for physical load, mean heart rate, peak heart rate. Live play is substantially more demanding than a 5on5 scrimmage in both physical and physiological attributes. Physical load was moderately greater (85%) in game play compared to a 5on5 scrimmage, and had a 12% higher mean heart rate, and the oxygen demand for live play was also substantially larger (30%) than 5on5. Accelerometers and predicted oxygen cost from heart rate monitoring systems are useful for differentiating the training and competition demands of basketball. Coaches can structure training with the knowledge that defensive and offensive drills will have similar training effects, while 5on5 scrimmages promotes game-specific training without compounding the overall demands of competition.

During basketball practice, there are striking similarities in the physical demands of defensive and offensive drills, but the intensity of these practice drills or activities are substantially lower than live play. The demands of weekly training and competition will result in decrements of repeat effort court-coverage ability within a season, and the demands tournament style play will negatively impact on performance and produce transient signs of muscle damage. Both of these detrimental aspects can be mediated by cold-water immersion recovery, but not compression garments. Future investigations could use the emerging accelerometry technology to define the contribution of the predominant plane of movement to total demand in both training and competition. Additionally, modelling of the combined physical and skill related performance decrements during the tournament environment would be invaluable in the holistic understanding of how accumulated playing loads contribute to skill and team success.
Declaration

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Paul G Montgomery
(14 December 2009)

List of publications

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<tr>
<td>a.u</td>
<td>arbitrary units</td>
</tr>
<tr>
<td>beat·min⁻¹</td>
<td>beats per minute</td>
</tr>
<tr>
<td>BI</td>
<td>Basic information</td>
</tr>
<tr>
<td>BM</td>
<td>Body mass</td>
</tr>
<tr>
<td>BIhr</td>
<td>Basic information and heart rate</td>
</tr>
<tr>
<td>BIhr+v</td>
<td>Basic information and heart rate and maxial oxygen uptake</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees celcius</td>
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<tr>
<td>©</td>
<td>Copyright</td>
</tr>
<tr>
<td>CHO</td>
<td>Carbohydrate</td>
</tr>
<tr>
<td>cm</td>
<td>Centimetres</td>
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<tr>
<td>CL</td>
<td>Confidence limits</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>CON</td>
<td>Control</td>
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<td>COMP</td>
<td>Compression</td>
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<tr>
<td>CWI</td>
<td>Cold water immersion</td>
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<tr>
<td>CK</td>
<td>Creatine Kinase</td>
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<tr>
<td>ES</td>
<td>Effect size (statistic)</td>
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<tr>
<td>FABP</td>
<td>Fatty acid binding protein</td>
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<tr>
<td>g</td>
<td>Gram</td>
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<tr>
<td>g·kg⁻¹</td>
<td>grams per kilogram</td>
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<tr>
<td>IL-6</td>
<td>Interleukin 6</td>
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<tr>
<td>IL-10</td>
<td>Interleukin 10</td>
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<tr>
<td>HR</td>
<td>Heart rate</td>
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<td>HRpeak</td>
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<td>h</td>
<td>hours</td>
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<tr>
<td>kg</td>
<td>Kilogram</td>
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<tr>
<td>kJ</td>
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<td>km·hr⁻¹</td>
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<tr>
<td>L</td>
<td>Litre</td>
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<tr>
<td>L·min⁻¹</td>
<td>Litre per minute</td>
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<tr>
<td>O₂</td>
<td>Oxygen</td>
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<td>Mb</td>
<td>Myogloblin</td>
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<td>m</td>
<td>Metre</td>
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<td>ml</td>
<td>Millilitre</td>
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<td>Symbol</td>
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<tr>
<td>min</td>
<td>Minute</td>
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<tr>
<td>min:s</td>
<td>Minutes and seconds</td>
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<tr>
<td>mmHg</td>
<td>Millimetre of mercury (pressure)</td>
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<tr>
<td>mmol·L⁻¹</td>
<td>Millimole per litre</td>
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<tr>
<td>PCr</td>
<td>Phosphocreatine</td>
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<tr>
<td>Pᵢ</td>
<td>Inorganic phosphate</td>
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<tr>
<td>pW</td>
<td>Predicted power in Watts</td>
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<td>s</td>
<td>Second</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SEE</td>
<td>Standard error of estimate</td>
</tr>
<tr>
<td>SWC</td>
<td>Smallest worthwhile change</td>
</tr>
<tr>
<td>TE</td>
<td>Typical error</td>
</tr>
<tr>
<td>™</td>
<td>Trademark</td>
</tr>
<tr>
<td>ml·kg⁻¹·min⁻¹</td>
<td>Maximal oxygen uptake (relevant to BM)</td>
</tr>
<tr>
<td>y</td>
<td>Years (of age)</td>
</tr>
<tr>
<td>yrs</td>
<td>Years (time)</td>
</tr>
<tr>
<td>VO₂</td>
<td>Oxygen uptake</td>
</tr>
<tr>
<td>VO₂max</td>
<td>Maximal oxygen uptake</td>
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<tr>
<td>W</td>
<td>Watts (power)</td>
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Acknowledgements

The undertaking of a PhD thesis is an investment in one's education and personal development that should not be taken lightly. When the planning, approval, research, writing, re-writing and frustrations are complete, what is the end result?

There are the letters that are afforded to the end of one's name for those who seek the recognition of their achievements, and rightly so; as the sacrifices made are numerous on both personal and financial levels.

There are the publications that come from the research which eventually comprises the thesis, these stand for one's level of creativity, scientific merit and critical thinking that is judged by their peers within the chosen field.

But the main outcome, I feel, is the process of the PhD itself. The completion of the thesis is a journey. A journey that challenges one's aptitude to appreciate the need for research in a certain area; the imagination to develop novel methods to obtain meaningful outcomes; the cognitive capacity to transcribe these outcomes into literature that has worthwhile applications; and tests one's patience, tolerance and perseverance.

A thesis teaches us to think. It teaches us the meaning and benefit of statistics, but most of all it teaches us that you cannot complete a thesis on your own. To complete a thorough list of acknowledgments would require several pages, as the people who moved through my journey are too numerous to mention. Nonetheless their individual contributions have not gone unnoticed. Their assistance in testing, data management, analysis, constructive criticism and thought provoking conversations come with sincere thanks.

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Chapter 1.

Introduction

A global study has shown that 212 countries and 450 million players compete in regular basketball competition and concludes that basketball may soon surpass football as the world’s most popular sport. Basketball is a court-based team sport played across all ages, genders and levels of ability. Involvement in the game ranges from small social games to highly-paid professional teams and major international competition. As with most sports that gain popular attention from media and supporters, the physical characteristics and fitness requirements of the players at high levels of basketball have increased substantially with the development of the modern game. From humble beginnings in 1891 as an alternative indoor exercise during inclement weather, elite basketball now has large amounts of funding in sports science and sports medicine support to ensure players perform at their peak. Despite the increasing popularity of basketball, and increased scientific involvement in team sport generally, the volume of peer-reviewed scientific literature relating to the physical and physiological demands of the modern game, and the competing athletes, is quite limited.

There are distinct differences in the anthropometric characteristics and physical capacities between playing positions for both male and female basketball players. The nature of basketball training and competition requires players to have well developed aerobic pathways. Peak aerobic power may be improved with basketball training; however, the repeated high-intensity, short duration efforts that characterise basketball competition require energy provision from anaerobic energy pathways. Once developed during the pre-season training period, anaerobic power is maintained during the competition season and appears to be the predominant energy pathway. Basketball is a dynamic intermittent exercise environment that elicits high heart rates and high blood lactate concentrations, which increase with higher levels of competition. Nevertheless, understanding fitness capacities is only an initial step in a holistic definition of the overall demands of training and competition.
The physical demands of junior and senior basketball tournaments have not been well documented, in particular how consecutive games over several days impact on physical performance and recovery. Intuitively, repeated games over several days create fatigue and muscular soreness in basketball players, however the origin and magnitude of this soreness have not been investigated, nor the potential benefits from recovery strategies aimed at minimising competition-related soreness. Physiological and psychological fatigue may compound to limit physical performance and skill execution required in basketball. Given that the body of literature on recovery is growing, little has been done to elucidate the effectiveness of contemporary strategies to minimise the detrimental effects of fatigue from a single, or multiple basketball games.

Understanding the physical demands of team sport can be more complex compared to physiologically steady state sports such as running, cycling and swimming. The nature of most court and field team sports including basketball is intermittent with movement and running characteristics that vary substantially in distance, velocity and intensity. Consequently the physiological responses to these demands are also highly variable, and quantitative assessment at any given time point is influenced by the preceding level of activity. Time-motion analysis has long been the gold standard for investigating the activity patterns for team sports, and basketball has not been an exception. Information gained from time-motion analysis studies provide instructive descriptive information, but may not fully enlighten coaches, athletes and practitioners to the overall physical and physiological demands of basketball. In order to provide coaches with information, studies measuring exercise heart rate and blood lactate concentrations were performed. Unfortunately, these two bodies of information were previously reported in isolation. A combined analysis of the physical demands together with the physiological response to training and competition is needed to understand the relationships between fitness levels, training and competition. In particular, the training environment forms a large component of the weekly exercise volume. Within these training sessions, the physical and physiological demands of drills and small-
sided games, which are related to specific aspects of play, have not been identified as to their intensity compared with actual competition. Information from these investigations is needed to develop more effective training programs for both junior and senior basketball players.

Sport technology has developed exponentially over the past decade, but like many sports, basketball has not embraced these developments. Heart rate systems which have telemetry capacity and the ability to provide detailed physiological information should provide insight into the demands of training and competition. Additionally, global positioning systems, accelerometers and magnetometers have been miniaturised allowing unobtrusive use by players during competition. However, basketball may be a sport that does not lend itself to extensive examinations from this type of sport technology, as the game relies heavily on perceptual awareness, team tactics and skill execution. Nevertheless, basketball has a large physiological and physical component that has not been investigated using predicted physiological information, or from movement sensors such as accelerometers respectively. Therefore investigation of training and game demands should reveal enlightening aspects for coaches and conditioning staff. Previously, only heart rate values and blood lactate concentrations were measured to determine the physiological demands of basketball. Another important measurement not previously examined is the aerobic demands of basketball training and competitive play. Many basketball programs implement a standard fitness test for peak aerobic power; either the Multi Stage Fitness (beep) test, or the emerging YoYo intermittent recovery test. These tests provide valid and reliable predictions of the player's peak aerobic power, but the rate of oxygen uptake during training and competition are not known. Commercially-available heart rate telemetry systems are emerging in the sport technology market that can provide real-time estimations of oxygen uptake during play. Although this technology has great appeal for those interested in quantifying the physiological demands of training and play, the validity and reliability of these systems has not been reported by independent research.
Basketball programs spend large amounts of resources to provide development pathways for young athletes. The rate of development of these young players ultimately determines the success of these programs. Although these programs are able to quantify improvements in basketball-specific skills, there is limited information in the understanding of development in physiological and performance measures. As players progress toward senior programs, routine physiological tests are conducted to quantify physiological development. Within these assessments, the line-drill test was developed as a measurement tool for court coverage ability. As the test incorporates speed endurance, repeat efforts and agility it is considered to have reasonable transfer into the fast transitional aspects of basketball play. Currently, it is unclear how performance in this test changes within, and between seasons. Progressive improvement in speed endurance and repeat effort ability within the line-drill after several years in a development program has not been documented. As the line-drill is common practice, providing detailed reference values based on gender and age, which contain the direction of any performance changes, along with the associated magnitude would assist coaches in their understanding of player development in this area.

Historically, investigations into sport physiology have been performed on those sports where energy provision is predominantly through aerobic pathways. Team sport physiology as a specific science has grown exponentially, however the understanding of the physical and physiological demands of basketball training and competition has failed to keep pace with the emerging science, and available technology. If the physiological and physical demands of basketball are to be fully understood, the use of emerging sensor technology in a practical context needs to be explored and validated in a systematic way. Additionally, a key feature of basketball competition at the highest levels is that games are repeated over several days. The fatigue related to these competition demands has not been investigated. Determining the pattern of performance decrements and identifying appropriate recovery will improve the physical preparation of players.
The current thesis is set out systematically to aid the reader in building an understanding of basketball. Following a review of the previous literature relating to the description, physiology and physical attributes of basketball and participating athletes; the experimental chapters follow a process of validation, investigation of performance during competition, describing the short and long term fitness capacity of players, and utilising novel technology to quantify differences in the practice environment. The initial process of validating new technology in chapter 3, to determine its effectiveness to quantify and describe the physiological responses to basketball training and competition is paramount. If unusable, the attributes of quantifying the demands of training and competition could not be investigated. Chapters 4 and 5 both investigate the performance demands and detrimental impact of tournament play. Chapter 6 describes the utility of a field test to monitor fitness of players, and chapter 7 closes the experimental work by using technology to explore the demands of basketball from a novel perspective. Appropriate discussions and conclusions are provided in chapters 8. The philosophy and experimental work contained within this thesis is based on applied sport physiology, and practical information designed to inform coaches and athletes to improve performance.
Chapter 2.
Literature Review

2.1. Description of basketball

An official basketball game involves two teams of 10-12 players, of which only five are allowed on the court at any one time during play. The objective is to move the ball down the court and into the opposition’s basket, which is fixed at a height of 3.05 m from the floor. Following a successful scoring attempt, the ball is turned over to the opposition which theoretically allows equal attacking and defending opportunities for both teams. Unlike other team sports which generally require a fixed number of players, basketball has characteristics which allow the game to be played 4 on 4, 3 on 3, 2 on 2 or 1 on 1 in the training environment, with full or half-court variations and unequal numbers per side to change the playing demands. These aspects make basketball a truly versatile sport, and contribute to the evolution of many sub-forms of the game for competition. This dynamic and evolving nature of basketball also underpins variations in training drills used to prepare players for competition.

The length of playing time depends on the level of competition; secondary-school games are broken into four quarters of 8 to 10 minutes in duration, collegiate games are played with two x 20-minute halves, and professional and international games comprise four x 10 and 12-minute quarters for females and males respectively, with a 15-minute break at half time and 2-minute break between quarters. The professional game for males therefore consists of 48 minutes of playing time. However due to stoppages, overall game time may be up to 2 hours with the total time on court being ~63 minutes, and actual live time played ~36 minutes (56% of total time). Stoppages occur for several reasons. First, the coach of a team may call a 60-second 'time out' when a break occurs in play. These time-outs are used strategically to implement appropriate patterns of offensive or defensive play, tactically to break the momentum of the opposition, and also to allow physiological recovery. Secondly, a player may commit a ‘foul’ on an opposing player. Fouls are classified as defensive or offensive;
defensive fouls occur when the defender blocks, pushes, trips, strikes or holds the player in possession of the ball.\textsuperscript{22} Offensive fouls are committed when an offensive player charges a stationary defender while in control of the ball, or pushes the defender away to increase the likelihood of receiving the ball.\textsuperscript{22} Generally, a player is allowed five personal fouls per game, six during international games, after which the player is removed from the game. Basketball is essentially a non-contact sport. However, physical contact often occurs when players contest for a loose ball in a limited space; therefore physical size and stature provide certain positional benefits. Player substitution is allowed at any stoppage during play, with no limit on the number of substitutions throughout the game. This rotation of players ensures that an appropriate player is on court for tactical reasons, or that accumulated fatigue does not impact substantially on player performance.

Basketball players have been categorised into the three positional groups of guard, forward and centre.\textsuperscript{4, 8, 24-47} This nomenclature is historically-based, and more recent terminology used in basketball defines players as either ‘perimeter’ (outside) or ‘post’ (inside). Players have been further classified into numerical sub-groups; 1 - play maker guard; 2 - shooting guard; 3 - forward; 4 - power forward and 5 - centre.\textsuperscript{28} Despite these classifications, there is little position-specific information on the movement patterns of each position, and the physiological requirements of these specific positions have not been well characterised in the modern game. Although there are physical attributes that are consistent across all positions such as jumping ability, each of these positions has specific physical requirements that indirectly define the role or tasks assigned to each player during a game. These attributes manifest into game performance indicators used in elite level basketball. Four discriminators have been defined\textsuperscript{48} that separate performance between positions; assists distinguish guards from forwards and centres, while greater volume of three-point scoring shots differentiate both guards and forwards from centres respectively. Offensive and defensive rebounds along with blocked shots separate centres from guards and forwards.
Guards are shorter and faster, and have greater agility and endurance than forwards and centres. Centres are generally heavier than forwards and require greater absolute strength, and repetitive power. Guards generally bring the ball down the court, control the offensive phase and organise teammates. As they are involved more in perimeter play, speed and agility are important attributes for guards to evade defenders. As guards generally play in an outside area of the court less concentrated with players, they are more likely to attempt field shots worth two or three points, compared with rebounding-type shots under the basket. Guards generally commit fewer personal fouls, and perform less rebounds and blocked shots.

Forwards play a dual role of perimeter play during offence and defence, along with competing under the basket for possession. These players possess both speed and agility, along with strength and stature to maintain position during contact situations. Forwards are considered creators of play due to their high number of passes. Their position in the offensive court builds an optimal passing angle to promote the ball closer to the basket. Forwards also interfere with the opponents’ offensive patterns through defensive structures designed to reduce opposition passing and interaction. Forwards also move continually within the defensive area to help their team mates during defensive play.

Centres are a focal point underneath the basket where tall stature allows them to get the ball into the basket easily and retrieve the ball (or rebound) from a missed shot. Clearly tall stature, mass, strength and power are important attributes for centres to gain and retain possession of the ball in both offensive and defensive situations. As close contact with the opposition is inevitable within the confines of the court, centres commit more personal fouls due to the nature of their position and interaction with offensive players when they attack the basket. Given the main task of a centre is rebounding and controlling the restricted space under the basket, typically they perform fewer scoring attempts from the field. Defining positional roles are also important within the tactical considerations during offence and defence. Knowing the location of team mates in relation to the ball, court and the opposition, allows players to combine the elements of their specific role in the team structure.
The athletic requirements that contribute to basketball performance include physical ability, motivation to succeed, and skill. However, the discrete skills and movement patterns involved differentiate basketball from other team sports. The ultimate goal is to shoot the ball into the basket with reliability, either from close range or from the perimeter. All members of an elite-level basketball team should possess above average spatial awareness, proprioception, decision making and balance capabilities. These attributes, combined with a unique set of physical and physiological characteristics separate not only players within certain positional roles but also basketball players from other athletes.

The physical demands of basketball require movement characteristics which are multi-planar. Not only is speed and agility required in positions such as guards, and power for forwards and centres, all players must meet the demands of repeated short, high intensity movements in forward and lateral directions. There are also concentric and eccentric demands associated with accelerating and decelerating in restricted court space. The regularity of explosive jumps also creates eccentric load and may lead to lower-limb stress injuries. The physiological demands of basketball can be characterised as intermittent and of variable intensity ranging from low to maximal. The intensity is influenced by game tempo, the quality of opposition, the style of play implemented by the coach, and the physiological capacity of the players. Existing investigations of intensity in basketball have been based primarily on heart rate. Peak heart rate values for males have been recorded between 165 – 187 beat·min⁻¹. The mean heart rate values during national level competition for males was reported at 169 beat·min⁻¹, or 89% of the peak heart rate determined during laboratory tests. Peak heart rates for females have ranged between 186 – 193 beat·min⁻¹. National level competition for females has an average of 177 beat·min⁻¹, ~91% of maximal. These preliminary results indicate the mean exercise intensity for basketball competition, but do not provide detailed information about the physiological or physical demands of the game. Given that heart rate responses during game play are relatively high compared with maximal values, players are required to have the capacity to tolerate repeated
bouts of play at an intensity that is close to, or above anaerobic threshold. The nature of basketball training and competition improves tolerance to this type of exercise due to the repeat efforts experienced at high intensity with minimal recovery. Measures of blood lactate concentration indicate that anaerobic glycolysis makes a significant contribution to the total energy demand during play. Typical peak blood lactate concentrations for males have been recorded at ~9 mmol·L\(^{-1}\),\(^2\)\(^3\) and during international level competition, female players may reach ~8 mmol·L\(^{-1}\).\(^8\) However, blood lactate concentration is not an adequate indicator of anaerobic metabolism, as lactate concentrations in the blood may be one third of the lactate concentration measured in the muscle.\(^5\)\(^3\) Moreover, these measurements are influenced by the exercise intensity immediately prior to sample collection, and are dependent on both lactate production and removal from the muscle. Nevertheless, blood lactate concentration has been used as a useful indirect marker of anaerobic glycolysis and intensity.

2.2. Fitness testing in basketball

The testing protocols used in this thesis are those endorsed by Basketball Australia for testing of national teams and elite junior development programs. Accepting that there are other protocols, and large amounts of data available (NBA Combine test data,\(^5\)\(^4\) SPARQ\(^5\)\(^5\)), this information does not necessarily mean that the tests in those protocols are the most effective for assessing capacity or capability. For each of the physical and physiological parameters assessed throughout the experimental chapters of this thesis, the large amount of comparative data available from Basketball Australia was one reason to promote the tests as detailed. Another reason for administering these tests was the familiarity to many of the participating athletes; this familiarity was thought to provide a greater reliability during testing as the participants would have had several familiarisations under actual testing conditions.

2.2.1. Speed

Speed has been shown as a predictor of playing time in male college level basketball.\(^3\)\(^5\) The most comprehensive information available on the speed characteristics of male players comes from NBA Draft testing program.\(^5\)\(^4\) Given that Basketball Australia also had large amounts of
data for a 20 m test, and that coaches from competing teams within these studies required comparative feedback of the Australian data for their players, it was decided that a test covering 20 m would be suitable for assessing speed.

2.2.2. Maximal aerobic power

Laboratory-based methods using metabolic carts are impractical for large playing rosters to routinely assess aerobic power. The limitations of such testing are the time constraints to test large groups; to complete this task would require several hours and this may impact on valuable court and coaching time. Access to a calibrated metabolic cart may be another limitation, as well as the cost associated to complete a single test, which may be hundreds of dollars per player. Within team sports, and basketball, the most common tool for assessing aerobic power has been the Multi-Stage Fitness Test (MSFT); commonly called the ‘Beep-test’ due to the audible beeps that determine the increasing running velocity. The MSFT has been reported to be a valid assessment tool for predicting maximal oxygen uptake (VO$_{2\text{max}}$), but may have some limitations when testing basketball players. Firstly, the test is continuous, increasing in running velocity after each level which lasts ~60 s. Basketball is more intermittent in nature; as players complete a transition from either offence or defence there will generally be a brief period of low velocity while the team organises their offensive or defensive structure. Secondly, the continuous nature of the test becomes more difficult for larger players, as they are challenged by the agility required to change direction quickly at faster velocities. Therefore a true reflection of VO$_{2\text{max}}$ may not be obtained as fatigue of the leg musculature occurs before cardiovascular fatigue. However the limitations for larger players will be the same on each testing occasion, and increased strength endurance of the legs will assist in obtaining a better score.

A more recent test has emerged as a substitute for the MSFT, and has also been found to be a valid predictor of VO$_{2\text{max}}$. Specifically, the YoYo Intermittent Recovery test, level 1 (YoYo) has been considered as a valid basketball-specific test for the assessment of aerobic fitness and game-related endurance, with good correlations to laboratory tested VO$_{2\text{max}}$.
(r=0.77, p=0.0001), speed at VO$_{2\text{max}}$ (r=0.71, p=0.0001) and %VO$_{2\text{max}}$ at Ventilatory Threshold (r=-0.60, p=0.04). The nature of this test is similar to the MSFT in that the running velocity increases at the beginning of each new level. However, the greater specificity of this test lies in the short 10 s walking rest that occurs after each out and back shuttle. This protocol closely replicates the events which occur during an on-court transition during play. For these reasons, this is the favoured test for assessment of VO$_{2\text{max}}$ throughout this thesis.

### 2.2.3. Anaerobic power and capacity

A wide range of tests have been used in basketball to assess anaerobic power and capacity. Assessments of anaerobic power for basketball players included vertical jumps using both power equations$^{41, 63}$ and force mats,$^{4, 34}$ 30-second Wingate anaerobic test (WAnT),$^{31}$ and a Magaria-Kalaman power test.$^{64}$ Anaerobic power and capacity is a physiological characteristic important to success in basketball playing performance. Given that previous testing in this area may have had little relevance and consideration for the running demands of the game, the suicide line-drill appears a likely solution to determine player ability in this area. Considering that basketball has a large running component, assessment within the experimental chapters of this thesis favoured the line-drill over previously used tests due to greater specificity to determine decrements in repeat-effort type running.

#### 2.2.3.1. Jumping ability

Jumping ability, when assessed by the several forms of vertical jump protocols is an anaerobic test of leg power. The most common forms of vertical jump tests are counter-movement based, where the athlete displaces their body mass downward, involving the stretch shorten cycle and immediately transfers their mass vertically to achieve maximal height. This action may be undertaken with or without the involvement of the arms. The arm swing in a traditional vertical jump-and-reach test may contribute ~10% to the jump height.$^{65}$ Strength training to the shoulder musculature may also contribute to jump performance. With
elimination of an arm swing the test focuses on leg extensor power, rather than a combination of power and skill. During basketball play overall jump height with arms extended is important, and a jumping action is often preceded by movement of one or both feet during situations of rebounding or jump-shot shooting. Another form of vertical jump testing employs a one-step jump or ‘gather step’ of the preferred foot. From a stationary position, the participant takes a step backwards with the one foot, assuming a preferred crouching depth. From this position the participant brings (gathers) the rear foot to the front and leaps as high as possible with one arm fully extended. While basketball probably has several different jumping actions during play and this test involves a degree of skill, jumping during competition against an opponent will also contain these skills. Therefore as this test is familiar to players and representative of game demands, the one-step vertical jump was chosen in this thesis.

2.2.4. Agility

Agility is a difficult component to assess in any team sport, the confounding variables of reaction, anticipation and the evasive actions of an opponent will all contribute to how effectively a player will change direction. In basketball, it appears that the most traditional test used is the T-test which has components of forward running, sliding in left and right directions, and backward running. The NBA Combine and SPARQ utilise the Lane-agility test (Figure 2.1), which comprises the same movement characteristics of the T-test, but employs them to assess how quickly a player moves around the key. However, the use of backwards running at high speed is questionable with respect to specificity, particularly in defensive periods of play in and around the basket. Basketball Australia have for several years used the Diamond agility test (Figure 2.2) developed by the Australian Institute of Sport. This test incorporates many situational movement aspects required within basketball play, the specificity of these movements implemented in a controlled environment will provide far greater information relating to speed and footwork required in basketball agility.
Figure 2.1. Graphic representation of the Lane-agility test. Not to scale.

Figure 2.1. Graphic representation of the Diamond agility test. Not to scale.
2.3. Physical characteristics of basketball players

The physiological and movement demands of a sport often determine the attributes and physical characteristics of the athletes who participate in that sport. The physical characteristics of basketball players are well documented\(^4, 8, 12, 24, 26-27, 29-47, 66-67\) with specific innate characteristics such as height, mass, arm span and muscle mass orienting players to one of the designated playing roles. Systematic appraisal of stature and body composition provides an objective framework to understand the distribution of muscle and fat mass within basketball players. Anthropometric measurements can be used to describe between-player differences in the designated positions and within- or between-player changes across seasons or training cycles.\(^67\) This section examines the physical and physiological attributes of the elite basketball player.

2.3.1. Height

Height differences among basketball players are well described\(^4, 8, 12, 24, 26-27, 29-47, 66-67\) and have obvious impacts on the positional roles during competition. For men, a broad analysis of the literature reveals guards are substantially shorter (187.2 ± 4.1 cm; mean ± SD) than forwards (198.4 ± 5.4 cm) and centres (206.9 ± 4.1 cm). The mean height of players increases across major levels of competition (Figure 2.3), with college players generally smaller (192.0 ± 8.0 cm) than national (195.4 ± 9.6 cm) and international (199.0 ± 2.9 cm) players.\(^{12, 41, 45-46, 67-68}\) Although there are gender differences in stature, the trends for positional height characteristics are similar for women; guards being (173.1 ± 5.6 cm), forwards (179.4 ± 9.7 cm) and centres (189 ± 12.3 cm). International-level female players are substantially taller (180.9 ± 0.09 cm) on average compared with national (175.4 ± 5.3 cm) and college (174.5 ± 5.2 cm) level players (Figure 2.3).\(^{25, 27, 29, 40, 42-44, 47, 67, 69-76}\)
Figure 2.3. Height (cm) trends for male and female basketball players based on position and level of competition. The solid lines represent the between-level trend for each position over the years of published data (1979 – 2008).
Figure 2.4. Mean height (cm) for male and female basketball players for main levels of competition based on the year of data collection. Error bars are removed for clarity.
2.3.2. Body mass

Consistent with the trends in height, there are positional differences associated with body mass. The published literature indicates that male guards typically have the lowest body mass at ~84 kg, followed by forwards at ~95 kg, and centres at ~105 kg.\textsuperscript{12, 41, 46, 67-68} Female athletes show a similar trend with guards, forwards and centres being ~68 kg, ~72 kg, and ~73 kg, respectively.\textsuperscript{25, 39, 44} There appears to be a maturation and developmental aspect as body mass increases slightly from college, to national and international level of competition (Figure 2.5). The increase in body mass would be related to both maturational effects and strength programs undertaken by national and international level players designed to increase lean mass. Comprehensive longitudinal monitoring of body mass for college-level Australian basketball players\textsuperscript{51} has taken place during their scholarship at the Australian Institute of Sport. This data is available through Basketball Australia and has shown lean mass varies across positions for men, with guards (40.2 ± 2.5 kg) having less lean mass than forwards (44.4 ± 10.2 kg) and centres (54.3 ± 3.6 kg). Lean mass measured in female college level players is 31.5 ± 3.5 kg. However, differences between perimeter (29.9 ± 2.8 kg) and post (33.5 ± 3.1 kg) players are evident from the information available.\textsuperscript{51}
Figure 2.5. Body mass (kg) trends for male and female basketball players based on position and level of competition. The solid lines represent the between-level trend for each position over the years of published data. Error bars are removed for clarity.
Figure 2.6. Mean body mass (kg) for male\textsuperscript{12, 41, 46, 67-68} and female\textsuperscript{25, 39, 44} basketball players for main levels of competition based on the year of data collection.
2.3.3. Percent body fat

The determination of percent body fat for basketball players has been calculated using hydrostatic weighing,\textsuperscript{27, 39, 43, 77} and estimations from skinfold measures using two\textsuperscript{24}, three\textsuperscript{78}, six\textsuperscript{25, 44}, seven\textsuperscript{68} and 15\textsuperscript{43} sites of reference. These methodological variations across studies make comparisons difficult given the differences in measurement error, underlying techniques, and derived prediction equations. Standard protocols\textsuperscript{79} and international standards (International Standards for Anthropometric Assessment; \textit{ISAK}) have now been implemented. These recommendations are based on a core group of measurement sites, and techniques that can be standardised. Variation among practitioners regarding the number of reference sites used, although based around the core group, and the technique used will be due to practitioners working in differing fields such as ergometry, nutrition and the exercise sciences. These practitioners may wish to stay with extended reference sites due to personal or professional preference, in that the additional information is relevant to their field. Additionally, practitioners may be confident with the measurement error that occurs with their technique. Future observations within the sport sciences working with basketball should follow the \textit{ISAK} protocols when performing assessments for clarity within, and between specific playing groups. In doing so, researchers following previous work can be confident that measurements are standardised, and that outcomes fall within acceptable tolerances for reliability and validity and confident comparisons can be made across studies.

There is little difference in the estimation of percent body fat between male positional groups, with guards (10.1 ± 1.6%), forwards (9.4 ± 1.3%) and centres (10.6 ± 2.6%) remarkably similar given the differences in stature and BM.\textsuperscript{12, 41, 51} The similarity in body fat probably reflects the larger amount of studies conducted on college and national level players. There is little information on percent body fat of international and professional basketball players. College-level players are still maturing and therefore, changes in body compartments and fluctuations in fat deposition due to training may not have stabilised.\textsuperscript{80} Of the available data, percent body fat is similar in college (10.3 ± 2.3%) and national (11.7 ± 0.4%) level
male players. Future studies into the player groups such as professionals and international players would provide useful information on the developmental aspects of basketball players from junior to senior international levels, and to establish criteria for success at these levels.

In contrast to men, body fat percentages reported for female players are generally higher and vary across position, with guards (16.3 ± 2.3%) and forwards (17.7 ± 0.3%) less than centres (19.5 ± 1.8%). Percent body fat has been claimed as the second most important discriminator of playing performance in women. In many contact sports, additional body fat is an advantage for collision protection and positional requirements. However, in sports such as basketball excess body fat may be a limitation to speed, agility, and explosive power unless proportional increases in force development are made.

2.3.4. Somatotype
The somatotype is a classification method for overall body physique and composition independent of body stature. Somatotype combines the three major components of adiposity (endomorphic) musculoskeletal (mesomorphy) and linearity (ectomorphic) into a three number rating. Somatotype classification provides an alternative perspective for player size and shape which is useful for academic and research purposes, however the practical utility that would guide coaches towards selection or recruitment is probably limited, as size and shape are self selection criterion for basketball positions, and may not necessarily reflect performance capacity.

There is limited information regarding the somatotypes of male basketball players. Generally, male basketball players are classified as ectomesomorphs, indicating they are taller with a larger musculoskeletal frame than the general population. Toriola et al. classified elite male basketball players with higher ectomorphic ratings, with no substantial difference in the mesomorphic component compared with other team sport athletes. Jelicic et al. also found that for elite junior basketball players, centres are predominantly ectomorphic compared with other positions, while guards are predominantly mesomorphic but generally
lower in all areas. Classification of Australian elite junior males reports that independent of position, these players are ectomesomorphic. Guards however, have substantially greater mesomorphy and less ectomorphy compared with forwards and centres.51

Elite female basketball players competing in World Championships or Olympic games have been profiled for their somatotype characteristics.70, 83-84 The first reports by Spurgeon et al.,84 revealed a substantial difference in somatotype between positions, with the differences more pronounced between centres and forwards compared with forwards and guards. An attribute common and important to basketball players is having longer lower limbs compared with trunk height, that promotes greater jumping ability. The somatocharts (Figure 2.7) of female players competing at the 1994 World Championships show a wide range of somatotypes at the elite level.85 Guards tend to be more muscular (mesomorphic) and less linear (ectomorphic) than forwards and centres. There were no differences between the positions for relative adiposity (endomorphic); this is in contrast to the data on percent body fat showing substantial difference across positions. This difference might be related to the small sample of elite players measured at the World Championships compared to the measurement of a broader population within the sport science literature.

The positional characteristics from the members of the top five teams compared to the bottom five teams competing at the 1994 World Championships were also examined. For the top four teams, guards (7 cm) and forwards (6 cm) were significantly taller while centres were not different to the bottom four teams.85 These differences have obvious tactical and scoring benefits, and the similarities in centres probably reflect a small homogeneous population group.83

More recently, Ackland et al.,83 reviewed elite female players and found a significant difference in absolute body size and type between positions. However, when segment proportions for centres and forwards were compared they possessed very similar characteristics for the upper body and lower body segment (with the exception of leg length), indicating that female forwards were a smaller version of centres. Centres and forwards also
had a smaller sitting height that was compensated by longer leg-lengths. This is an advantage in meeting game demands for jumping, but not for agility as the player’s centre of gravity is relatively high. In contrast, guards have greater proportionality of lower limb to trunk, and thus a lower centre of gravity enabling them to be more effective in their faster, agile playing roles.

Basketball players appear to fit a specific body profile, and this is more pronounced in males where linearity is the defining feature compared to females who may have a wide range of profiles. Although the key elements of male and female basketball play are the same, the athletic demands are considerably different, and the requirement to have a taller, larger frame may be self-selecting criteria which orientates males with these characteristics to the game. Adiposity is not common among these athletes, indicating that the high demands of the sport do not allow large amounts of fat deposition, or suit body types that are shorter and more rounded. Although interesting, the information gathered from somatotype profiling has limited application in basketball research. The relationship of a somatotype profile to key physiological variables such as aerobic capacity would appear to offer no further insight to performance capability than height, BM, skinfolds and percentage body fat.
Figure 2.7. Somatochart of female guards (a), forwards (b) and centres(c) competing at the 1994 Female World Championships. Gratefully reproduced with permission, from Carter et al.,70 http://www.tandf.co.uk.
2.4. Physiological profile of basketball players

Physiological testing of basketball players allows for the construction of position-specific profiles, monitoring the effectiveness of training programs, identifying positive or negative skill acquisition and aid talent development. These tasks are important for enhancing performance, minimising injury risk, and increasing the longevity of a player’s career. Information gathered during routine physiological testing can also be compared to competition intensity to determine whether the demands of training are matching those of games (i.e. specificity of training). Although standardised tests are now well documented, information in the existing basketball literature is difficult to interpret due to inconsistency in the protocols used; implementing a full range of assessments using standardised protocols would allow future researchers and practitioners to interpret their findings against previous results.

2.4.1. Speed

Speed has been shown as a predictor of playing time in male college level basketball. Speed characteristics in games have not been well characterised, particularly for women. The NBA Combine test protocols possibly have the most comprehensive historical data on male players aspiring to elite competition. The speed test used by the NBA draft assesses players over 22.86 m. These players will generally be from college programs and regardless of position, will cover this distance in 3.29 ± 0.14 s. Previous investigators have reported sprint times in basketball fitness or physiological testing over 50 yd, 40 yd, 30 yd, and 20 m. It seems that historical or comparative insights to other sports may explain the use of a 40 yd or 50 yd (36.5 m and 45.7 m) measure, as these distances are unrelated to the sprint distances encountered by basketball players, and are substantially longer than the court itself. The 30 yd (27.4 m) measure is more consistent with the court dimensions and may serve as a useful comparison. Over this distance, college level male guards (3.68 ± 0.14 s) were significantly faster than centres (3.97 ± 0.21 s), and forwards (3.83 ± 0.16 s) were not substantially different from either guards or centres.
Tests over shorter distances (20 m) show less discrimination across some positional groups, with male guards (3.03 ± 0.07 s), forwards (3.08 ± 0.12 s) achieving similar sprint times, however centres (3.29 ± 0.18 s) have a moderate but substantial slower 20 m sprint time. This lack of difference may be due to the very short distance that precludes smaller, faster players from attaining maximal velocity from a stationary start. Although this test may represent a typical sprint distance during a fast break situation, it should only be interpreted as a measure of acceleration rather than maximal velocity, as team sport athletes often reach maximum velocity at approximately 40 m. Information regarding female sprint ability over any distance in basketball is scarce. Generally, 20 m sprint time for female players is 3.40 ± 0.10 s. Given that it would be unlikely that basketball players would ever reach maximal velocity from a stationary start during play, tests longer than ~20 m as described here would be of little use to coaches and sport scientists working in basketball. The explosive speed characteristics that are required are adequately addressed in a test over 20 m.

2.4.2. Maximal aerobic power
Endurance is an important physiological characteristic necessary for basketball performed at a high level. The maximal oxygen uptake (VO\textsubscript{2max}) is the rate at which exercising musculature uses oxygen; the maximum rate at which an individual can consume oxygen is an important determinant in physical work capacity in many sports. VO\textsubscript{2max} is typically expressed in absolute terms as litres of oxygen per minute (L·min\textsuperscript{-1}) when total power output is a major consideration, or in non-weight bearing sports such as rowing. When body mass needs to be considered, VO\textsubscript{2max} is expressed in millilitres of oxygen per kilogram of body mass per minute (ml·kg\textsuperscript{-1}·min\textsuperscript{-1}). A moderate to high VO\textsubscript{2max} is required during basketball play, as the debilitating effects of anaerobic glycolysis from the intense interval or ‘burst’ nature of the sport can be offset by a greater energy provision from aerobic pathways. Whilst the ability to maintain the repeat effort nature of basketball play may be attributed to several factors, the accumulation of intracellular inorganic phosphate (Pi), and creatine phosphate (PCr) availability appear to be the likely determinants. The fact that PCr resynthesis, and
intracellular $P_i$ removal via phosphorylation are aerobic processes suggests that a high $VO_{2\text{max}}$ may enhance a player's ability to resist fatigue during high intensity repeat effort play.

The $VO_{2\text{max}}$ of male basketball players ranges from 43 to 65 ml·kg$^{-1}$·min$^{-1}$ (Figure 2.8). This broad range may relate to differences in conditioning programs and playing styles, playing standard or level of competition, and differences among measurement environments (i.e., field vs. laboratory) and metabolic cart systems. For practical reasons, the field-based 20 m MSFT has been extensively used to determine the endurance capacity of basketball players and to estimate their $VO_{2\text{max}}$ with high validity and reliability. The nature of the test with many direction changes, increases the specificity of the test to the demands of the game compared with a laboratory-based, progressive treadmill running protocol.

Hoffman et al. showed an inverse relationship between $VO_{2\text{max}}$ and playing time, that is, players with higher $VO_{2\text{max}}$ had less playing time. This research also speculated that above a certain level, $VO_{2\text{max}}$ has no additional benefit to increasing playing performance. Although a high $VO_{2\text{max}}$ has intuitive benefits for meeting the oxygen demands of training and competition, these observations raise the question of what is an appropriate $VO_{2\text{max}}$. The aerobic energy system plays an important role in recovery following anaerobic exercise, and should therefore allow players to meet higher on-court playing times and the accumulated demands of high-intensity play. Contrary to the outcomes of previous research, a higher $VO_{2\text{max}}$ should favour a player being afforded more game time, as a higher capacity will allow faster recovery and re-entry into the game. A fitter player may also be less susceptible to fatigue induced decrements in skill performance.
Figure 2.8. Mean \( \text{VO}_{2\text{max}} \text{ (ml·kg}^{-1}·\text{min}^{-1}) \) for year and level of competition for male\(^{12, 24, 31-32, 36, 40, 45, 51, 89-91}\) and female\(^{4, 8, 25, 27, 29, 39, 42-44, 47, 51, 67, 69, 71}\) basketball players, for main levels of competition, based on the year of data collection.
In comparing maximal aerobic power among positions, the literature on national and college level players indicates that male guards tend to have greater mean values of (58.7 ml·kg⁻¹·min⁻¹)₁², ₅₁, ₇₇ than forwards (49.5 ml·kg⁻¹·min⁻¹)₅¹, ₇₇ and centres (47.5 ml·kg⁻¹·min⁻¹).₅¹, ₇₇. There appears to be a significant difference in VO₂max among positions for females, with perimeter positions 1 and 2 (54.3 ml·kg⁻¹·min⁻¹) having greater VO₂max than post positions 3, 4 and 5 (48.9 ml·kg⁻¹·min⁻¹).⁴⁴ Maximal aerobic power is also a performance predictor in female basketball, discriminating between high and low level skilled players,⁴³ and increases across level of competition from ~47 and 49 ml·kg⁻¹·min⁻¹ at college and national levels, to ~50 ml·kg⁻¹·min⁻¹ at international level.⁴, ₈, ₂₅, ₂₉, ₃₉, ₄₂-₄₄, ₄₇, ₅₁, ₆₇, ₆₉, ₇₁ Yearly representation of VO₂max data shows that there has been no temporal increase for both males and females in recent years (Figure 2.6). This interpretation is limited by the lack of consistent data collected across levels of ability, particularly professional and international levels.

Maximal oxygen uptake can increase⁴₀, ⁴₅ during the pre-season period, and then be maintained,⁶₆, ⁹₂ or decreased⁴⁵ back to levels not different from pre-season values over the playing season. These changes possibly reflect the high-volume aerobic based training that occurs in the preparation phase and a shift to repeat effort, anaerobic type exercise as the season progresses to competition phase. This progression may facilitate a physiological plateau in aerobic requirements which underpins greater anaerobic pathway utilisation. Therefore, during the repeat effort nature of basketball play, although there is a progressive increase of the aerobic contribution to energy supply with increased efforts, the level of energy supplied via aerobic pathways may still be considerably less than overall energy demand, with the balance met by anaerobic pathways.⁹₃

Indirect estimations of oxygen uptake have been attempted using heart rate in other team sports.⁹₄ These initial investigations are limited by the nature of the intermittent exercise experienced in team sport, and that heart rate increases disproportionately to oxygen uptake.⁹₅ Due to the upper-body involvement in specific basketball movement patterns, and cardiac drift,⁹₆ estimating oxygen uptake using regression models from heart rate can be problematic.
However, the recent development of heart rate systems that employ algorithms to predict oxygen uptake and energy expenditure based on neural networks constructed from R-R heart beat intervals, R-R derived respiration rate, and the on-and-off VO$_2$ dynamics during various exercise conditions,\textsuperscript{18, 97-98} may prove insightful in understanding the oxygen demands of basketball. This may eliminate the limitation of using interpretations from linear regression estimates of VO$_{2\text{max}}$ from heart rate. As these systems have not been independently evaluated for their validity and reliability, further investigation is required using these systems in the training and competition environment to determine their effectiveness.

2.4.3. Anaerobic power and capacity

Game success may be determined by a player’s ability to sustain high intensity demands during play. Basketball play consists of repeat efforts, vertical jumps and rapid changes in direction that can discriminate players of different performance levels.\textsuperscript{35} Measures of anaerobic power during a 30-second Wingate Anaerobic Test (WAnT) reveal that results for basketball players are consistent with other team sport athletes.\textsuperscript{38} The ability to maintain repeated high intensity efforts in basketball can be improved through specific conditioning of the anaerobic energy systems. Specific conditioning drills, and small sided games which involve high volume repeat effort running with various rest periods, would stress energy systems at the anaerobic threshold, contributing to these fitness outcomes. Anaerobic power when measured in a jump, or modified stair climb can increase by ~10% over a pre-season training period and then be maintained during the playing season.\textsuperscript{4, 45, 64} This training effect is opposite to VO$_{2\text{max}}$ which increases over the pre-season but falls back to initial levels during the competition season.\textsuperscript{45} The maintenance of anaerobic power and a decrease in VO$_{2\text{max}}$ support other research indicating that aerobic power may not have further practical benefit in basketball above a certain level.\textsuperscript{35} Comparisons in repeat sprint ability between team sport and endurance athletes made by Bishop & Spencer\textsuperscript{99} found that team sport athletes were able to produce greater peak power and total work during a 5 x 6 second repeat sprint test than endurance athletes matched for aerobic power. Therefore, the ability to maintain intensity
during periods of high demand basketball play is probably met from sport specific development of anaerobic pathways. These developments are possibly due to enhanced creatine phosphate resynthesis, and decreased inhibition of glycolytic enzymes.\textsuperscript{99-100} Given the importance of anaerobic metabolism to performance and outcome during basketball play\textsuperscript{43} it is surprising that there has been limited testing of anaerobic power/capacity within basketball programs and inconsistent information reported, particularly at the professional levels. The number of players involved in a basketball roster may preclude laboratory testing of these attributes; therefore a practical field-based test for anaerobic power and repeat sprint-ability involving basketball-specific repeat efforts may be more useful.

The Suicide line-drill is a court-based repeat effort test lasting approximately 30 s depending on an individual’s playing position and gender. The test has the advantages of being a commonly used conditioning drill during training, and that several athletes can be tested simultaneously. Although only previously suggested as a test of anaerobic capacity,\textsuperscript{101} Hoffman et al.,\textsuperscript{32} have confirmed that the line-drill is highly correlated with jump tests and power from WAnT. The contribution from glycolytic anaerobic pathways during the WAnT was reported at 56%, with the phosphagen and aerobic pathways contributing 28% and 16% respectively.\textsuperscript{102} Therefore, based on the maximal effort intensity during the 30 s time frame of the test, the suicide line-drill appears predominately anaerobic, with glycolysis as the primary pathway. Therefore the test should be able to discriminate the repeat effort ability among basketball positions. From the limited literature available, men generally complete the test in ~28 s. There is a substantial difference between positions with male guards faster (26.7 ± 0.1 s) than forwards (28.3 ± 0.6) and centres (29.4 ± 0.1).\textsuperscript{51} Differences among positions can be explained partly by anthropometric measures; the stature and body mass of taller players limits their ability to move over the court with the same agility and speed compared to other positions. However, within a positional group the player who possesses a greater ability in the line-drill test should be able to compete for longer, and at a higher intensity compared to an opponent who performs the line-drill test with less ability.
For female players, anaerobic capacity is a key physiological characteristic which can differentiate between players of high and low playing performance. This difference may be attributed to characteristics of better players maintaining skill while being able to cope with the repeat effort demands of the game, as better players have greater a shooting percentage. Similar to male players, regardless of the apparent importance of this physiological characteristic, there is limited information regarding anaerobic capacity in female basketball players. Assessments of anaerobic power have been made using vertical jump tests in college and national level teams. Smith & Thomas 1991 reported large differences between national level guards and forwards only using both the vertical jump (~8 cm) and the line-drill (~2 s) protocols.

Anaerobic power and capacity is a physiological characteristic important to success in basketball playing performance. Given that previous testing in this area may have had little relevance and consideration for the running demands of the game, the suicide line-drill appears a likely solution to determine player ability, and future assessments should favour this test especially in females who have received little attention in this area.

2.4.4. Jumping ability

The vertical jump, in its several forms, is an anaerobic test of leg power which has been shown as the highest predictor of playing time in male college level basketball. Together with stature and overall reach height, jumping ability provides a competitive advantage during rebounding and shooting. Male jumping ability has been reported as high as 105.4 cm, however the mean jump heights from the available literature is 63.5 ± 9.8 cm. The substantial variation in jump ability is likely due to differences in the jumping protocol and the assessment methods (i.e. chalk board vs. Vertek, Yardstick vs. timing mat, and gather step vs. counter-movement jump). Vertical jump protocols using a ‘Counter Movement Jump’ or ‘Squat Jump’, measured by means of contact mat and digital timer, are the most reliable and valid field tests for the estimation of lower limb explosive power.
Vertical jump performance decreases as positional stature increases, regardless of gender. College level male guards (71.2 ± 3.2 cm) have greater jumping ability than forwards (68.3 ± 4.8 cm) and centres (66.5 ± 3.4 cm). Similarly, female guards (49.7 ± 2.2 cm) are greater than forwards (46.2 ± 2.7 cm) and centres (45.6 ± 3.4 cm). Earlier information reported little difference in the average jumping ability between college (45.2 ± 2.7 cm) and national (44.7 ± 5.3 cm) level females. More recent reports are consistent with these findings, with college (43.8 ± 4.3 cm) and national (44 ± 13.1 cm) levels remaining similar, however the inclusion of international standards has revealed a substantial difference in jumping ability (49.9 ± 7.3 cm) at this level. It would appear that increases in jump performance over recent years are evident particularly at the female college level (Figure 2.9).
Figure 2.9. Mean jump height (cm) for male 24, 30, 32, 35-36, 40-41, 51 and female 4, 25, 27, 39, 42-44, 51, 67 basketball players, for main levels of competition, based on the year of data collection.
An estimation of power (W) can be achieved by applying various formulae to the vertical jump score.\textsuperscript{104-105} However care should be taken in the implementation of these formulas as there can be wide variation in the prediction of power (Table 3). An estimation of mean peak vertical jump power for males across all positions has been calculated using the Lewis formula.\textsuperscript{106} However as this method can produce very large underestimations of peak power, these results are not a true reflection of leg power for basketball players. An analysis using the formula of Sayers et al.,\textsuperscript{105} showed that guards (6108 ± 67 W) were less powerful than forwards (6667 ± 458 W), and forwards less powerful than centres (6924 ± 144 W). Differences in estimated power did appear across levels of competition with college (6303 ± 812 W) greater than national level players (5758 ± 113 W), although this may be biased by the large sample number influenced by the NBA Draft at the college level.

Power estimates for females have not been reported previously; guards (4052 ± 281 W) forwards (4017 ± 345 W) and centres (4040 ± 530 W) are remarkably similar.\textsuperscript{25, 39, 44, 51} Although data is limited it appears there is also little difference in power between college (3660 ± 397 W) and national (3487 ± 859 W) level female athletes. However, international-level athletes have considerably greater (4033 W) peak power. Power output is lower in adolescents compared to adults, partially due to the distribution and differences in muscle mass.\textsuperscript{107} Therefore, morphology and physical maturation could explain why there are differences across not only the level of competition, but also among positions, as the association between maximum strength and power is influenced by body mass.\textsuperscript{108} Centres are larger athletes in both stature and body mass and therefore they have greater muscle mass, which affords them the ability to produce greater power (as described above). Older athletes in national and international competition appear to have developed greater muscle mass through maturation and specific conditioning.
Agility is a difficult athletic component to describe and quantify. Qualities that define an agile basketball player include the ability to change direction with minimal loss of velocity, accelerate and decelerate within a minimal distance, and good proprioceptive foot movement for balance and coordination for weight transfer during evasive movements. Of the two main contributors to agility in the model proposed by Young et al., the factors that underpin change of direction speed outweigh the perceptual and decision making factors required to anticipate, or create a change of direction. Although strength and power are components within the model that influence change of direction speed, these attributes have only a trivial correlation with speed or effective change of direction. Reactive strength of the leg musculature, as measured by a drop jump, played an important role in an 8 m sprint test with

<table>
<thead>
<tr>
<th>Position</th>
<th>Sayers $^{105}$ (pW)</th>
<th>Lewis $^{104}$ (pW)</th>
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<tr>
<td>Males</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards $^{41, 51, 54}$</td>
<td>6108.3 ± 67.2</td>
<td>1549.6 ± 16.0</td>
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<tr>
<td>Forwards $^{41, 51, 54}$</td>
<td>6420.6 ± 253.3</td>
<td>1807.6 ± 149.4</td>
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<tr>
<td>Centres $^{41, 51, 54}$</td>
<td>6718.0 ± 144.4</td>
<td>1926.5 ± 84.9</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards $^{25, 39, 44, 51}$</td>
<td>4052.6 ± 281.9</td>
<td>1042.2 ± 81.3</td>
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<tr>
<td>Forwards $^{25, 39, 44, 51}$</td>
<td>4017.6 ± 345.8</td>
<td>1058.6 ± 131.9</td>
</tr>
<tr>
<td>Centres $^{25, 39, 44}$</td>
<td>4040.1 ± 530.6</td>
<td>1068.8 ± 179.3</td>
</tr>
</tbody>
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four changes of direction. Asymmetry of leg reactive strength also showed that greater strength of a particular leg would benefit change of direction to the opposite side. Therefore knowing the preferred side of a player or opponent provides insightful information for player development and competition tactics; clever coaches can position players on the court to take advantage of their ability. Additionally, knowing the attributes of an opponent can provide an advantage to the smart defender in isolating a player to negate their change of direction speed. From a development perspective, programs can be implemented to improve bi-lateral strength to enhance agility on both sides of the body.

Given that there are numerous movement changes during basketball, the ability to move quickly and efficiently, to both sides of the body within the limited court space is critical. Quantitative information on the agility of basketball players is scarce. A survey revealed that only 7% of NCAA college programs used an agility test.41 This is surprising considering that agility measured using a T-test protocol was a moderate to large indicator of greater playing time at college level.35 Most published reports of agility have used the T-test which has components of forward running, shuffling in left and right directions and backward running. Mean scores across all position groups are 9.9 ± 0.9 s;35, 41, 110 however a closer analysis would probably differentiate positions. The NBA Combine pre-draft testing program employs the Lane-agility drill,54 this test requires players to move around a rectangular area within the key measuring 5.79 m x 4.88 m. Starting from the foul line, players run forwards to the baseline, side shuffle right, backwards to the foul line and side shuffle left to the starting position where they touch the ground and repeat the test in reverse. Small positional differences are evident from this test with guards, forwards and centres completing the test in 11.3 ± 0.5, 11.6 ± 0.5, and 11.9 ± 0.7 respectively.54 These outcomes may in themselves be a limitation for the use of this test if it cannot adequately discriminate performance between positions. A recently developed agility test (Diamond-agility test; Australian Institute of Sport, unpublished observations) which combines forward running, side shuffling, and drop steps off both feet shows greater utility in respect to the specificity of movement required for
basketball agility around and under the basket. This test also shows substantial difference among positions with male guards, forwards and centres completing the test in $6.2 \pm 0.1$, $6.7 \pm 0.2$ and $6.8 \pm 0.3$ s respectively. Analysis of Australian females$^{51}$ indicated a substantial difference for players competing in the perimeter ($6.4 \pm 0.2$ s) and post ($7.0 \pm 0.3$ s) positions. These results confirm what is intuitively known that perimeter players, either male or female, have better agility which is likely due to their lower centre of mass and faster speed.

Conjecture will always be present during the selection of a performance test. The three tests discussed here all comprise movements that are expected within basketball; however it is the application and similarities of the test to specific situational aspects of play that promotes one test over another to provide coaches and practitioners with meaningful information. The T-test and the Lane-agility test provide forward and lateral movement specifics, but the use of backwards movements at high speed is questionable with respect to situational relevance, particularly in defensive periods of play in and around the basket. Additionally, the protocol for the Lane-agility test requires players to run away from the foul line to the base line; surely an astute scientist working with basketball would recognise the meaningless context of this protocol and look for alternatives. The last test described requires players to run from under the basket to the top of the key, side shuffle, drop step and run forwards back to the basket. These movements replicate situational aspects of the game where a player would be required to run to defend and close-out an opponent, side shuffle to one side maintaining a defensive position, and turn to rebound under the basket. A test which incorporates as many situational movement aspects required within a sport, and can implement those movements in a controlled situation will provide far greater information than a test that is designed only to test ‘agility’, and as such a test will only be assessing balance and coordination.

2.5. The physiological demands of basketball play
Although the movement characteristics of basketball have been documented previously, little is known about the combined physical and physiological intensity during offensive and defensive movements, and periods of game play. A detailed understanding of the movement
patterns and physiological demands of competitive basketball is needed for prescription of game-specific training programs. Measurement of heart rate and blood lactate concentration has been the main focus of physiological investigations into the demands of basketball play, but higher level investigations are required to provide additional physiological information.

2.5.1. Heart rate responses
Heart rate during basketball may be influenced by the internal processes of the athlete such as nutritional status, dehydration, anxiety and fatigue, and external factors of environmental conditions and intensity of play. Heart rate should therefore be considered an indirect measure of intensity. Elevated heart rate values during basketball may be observed regardless of the velocity or distance of movement during play. The isometric application of force during contested situations creates high physiological strain and corresponding elevations in heart rate.

A range of heart rate values during play have been documented at 155 – 190 beat·min⁻¹ for male and 154 – 195 beat·min⁻¹ for female college players. Two studies investigating the heart rate response in European first division males revealed mean levels during play of ~172 and ~167 beat·min⁻¹. The most recent report supports these values, with mean heart rates of ~171 beat·min⁻¹, or 91% of the maximal heart rate recorded during play. Differences in mean heart rate response between positions were significant for guards (174 beat·min⁻¹) and centres (169 beat·min⁻¹). During on court playing periods, 75% of this playing time was at or above 85% of maximal heart rate, with an average of 169 ± 9 beat·min⁻¹.

Females competing at Australian national level had a peak heart rate of 193 ± 3 beat·min⁻¹, with an average during play of 177 ± 1 beat·min⁻¹ which is ~91% of maximal. More recently Rodriguez-Alonso et al., revealed no substantial difference in mean heart rate between positions, and level of competition during female basketball play. During international games, female players obtain average heart rates of 95% of maximal compared to national levels games which average 91%. This information shows that the heart rate
response to positional characteristics and workloads varies little within a team, and level of competition.

2.5.2. Blood lactate concentration

Lactate is a by-product of anaerobic glycolysis, and its measurement in peripheral blood reflects a balance between production in muscle, entry into the blood, as well as the removal out of the blood. Thus, the measurement of blood lactate concentration does not account for lactate used in other metabolic energy pathways (e.g., Kreb’s cycle), or as an energy substrate by other muscles (e.g., respiratory muscles) and organs (e.g., liver, heart). Therefore, blood lactate concentration is an indirect estimation of glycolytic involvement, rather than a true indication of the degree of glycolysis. Measuring lactate in dynamic team sports such as basketball is difficult as any particular sampling point is influenced by the intensity and activity preceding the sample. The inter- and intra-individual positional differences affecting the way in which lactate accumulates during basketball are two limitations for the use of lactate to describe the demands of basketball. Diet, muscle glycogen, dehydration and temperature can influence interpretation. Exercising with damaged muscle can also increase lactate concentration,\textsuperscript{115} and this is another consideration given the eccentric loads and repeated games experienced in basketball. Despite these limitations, blood lactate concentration has been, and will continue to be used as a crude indicator of glycolytic involvement and exercise intensity.

Several studies of national and college level competition have shown a decrease in lactate concentration of \(~1.5\text{ mmol·L}^{-1}\) in the second half of play.\textsuperscript{37, 116-118} National level Australian males average \(6.8 \pm 2.8\text{ mmol·L}^{-1}\) during play, with mean peak values across all positions of \(8.5 \pm 3.1\text{ mmol·L}^{-1}\), however an individual peak was as high as \(13.2\text{ mmol·L}^{-1}\).\textsuperscript{23} With a large standard deviation, and the highest value \(~5\text{ mmol·L}^{-1}\) above the mean, this variation highlights the limitations of lactate sampling and its utility in describing intensity. Australian females competing in national level competition had an average blood lactate concentration of \(5.7\text{ mmol·L}^{-1}\).\textsuperscript{52} During national and international level female games, greater playing time
was associated with higher lactate concentration, with guards (6.5 ± 2.1 and 6.2 ± 1.5 mmol·L⁻¹) attaining higher levels than forwards (4.9 ± 1.8 and 5.2 ± 2.2 mmol·L⁻¹) and centres (3.7 ± 2.0 and 4.6 ± 1.9 mmol·L⁻¹ respectively). This information reflects the relationship of glycolytic involvement between positional roles and standard of competition. Presumably guards have considerably more explosive movements and less stationary time than forwards and centres which contributes to higher lactate concentration. However, if the corresponding values can be considered as a measure of intensity, there appears to be little difference between national and international female play.

2.5.3. Time-motion analyses

Time-motion analyses of the movement dynamics and characteristics in basketball play have not been well documented in the past. Intuitively, time-motion analysis appears an effective tool for determining the demands of basketball, however this method has limitations. Time-motion analyses may over simplify movements into categories, when the demands of play are less structured and require dynamic contributions of many body segments. Additionally, inconsistency of interpretation will impact on the desired outcomes; therefore a high degree of validity and reliability between investigators in time-motion studies is required. The gross movement characteristics in men’s national and first division European basketball have been reported by several researchers. The total distance covered per game in one study equated to 4583 meters, and when divided into locomotive categories, walking comprised 1160 meters (25.3% of total distance), jogging 2247 meters (49% of total distance), moderate-speed running 1355 metres (29.5% of total distance) and high-speed running 500 meters (10.9% of total distance). McInnes et al., reported that walking, moderate and high-intensity activity accounted for 35%, 22% and 15% of live time respectively. Although Janeira & Maia did not discriminate between high intensity movements, and there may be errors associated with different quantification techniques related to game times and country-specific styles of play, the results may indicate that the movement characteristics of basketball have increased since the earlier 1995 study of McInnes et al.
Frequency analysis of the movement activities for Australian national league players revealed that the occurrence of walking is 295 times, jogging 99 times, moderate-speed running 107 times and high-speed running 105 times. The duration of these movements are relatively similar, with walking instances lasting 2.5 s, jogging 2.5 s, moderate-speed running 2.3 s and high-speed running 1.7 s. More recently, a detailed analysis showed that walking occurred 129 times, jogging 113 times, and although moderate and high-speed activities were classified differently to the previous movement analysis studies, the instances were 197 and 94 respectively. The important comparison was that the duration of these activities were very similar to previous research. Walking events lasted 2.4 s, jogging 2.2 s, moderate 1.9 and sprint 2.1 s. The differences in the quantification methods for the various activities highlight the possible inconsistencies with time-motion analysis. However it may also indicate that the acute demands of these activities have not changed substantially, but there is a greater requirement of continuous running, highlighted by more continuous moderate speed efforts, less walking and fewer high speed efforts.

2.5.4. Basketball tournament play
The demands of competitive basketball tournament play where teams play several games over several days have previously been unexplored. The weekly activity of basketball players during the competitive season entails a cycle of training, recovery and competition. At the elite level this weekly cycle may involve one, two or three games in as many days. During national and international competition, basketball tournaments usually consist of several games played on consecutive days. Repeating high-intensity games over several days intuitively creates fatigue and performance decrements, decreasing a team’s competitive advantage. Throughout the 2007 Women’s World Basketball Championship, the winner had to play 9 games in 12 days, with the initial pool games played consecutively over three days. It was not until the final rounds that players were afforded a rest day between games. During international competition where the top teams are relatively equal in skill and tactical execution, the maintenance of physical performance and limiting fatigue may be the deciding
factors for success. This requirement highlights the need for well structured recovery programs in the initial tournament stages to ensure competitive ability is maintained at a high level for advancement into the finals.

During multi-game tournament play, cumulative fatigue may contribute to teams being less competitive after several days of play. Recently, investigations of the statistical factors discriminating winners and losers in college level tournament play revealed that 3-point perimeter shooting was a successful characteristic of winning teams after three consecutive games.\textsuperscript{14} This outcome was suspected to be due to higher conditioning of the winning team, or decreased fitness of the losing team, as the defensive players may not have made position to pressure outside shooting. The authors concluded that there was no accumulated fatigue effect after three games, as there were no differences in many of the skill-based discriminating variables. However, these conclusions seem contradictory as the authors also claim that fatigue of losing teams may be a reason for improved shooting of their opponents.\textsuperscript{14} It appears that accumulated fatigue is a feature of tournament play, and impacts negatively on a player’s capacity to move effectively.

\textbf{2.6. Fatigue}

In physiological terms, fatigue is characterised by homeostatic disruption to the cardiovascular, central and peripheral nervous systems, metabolic and muscular systems.\textsuperscript{123} Determining the individual contribution to fatigue from these systems is complex, but it is generally understood that a multifaceted interaction may result in a loss of performance in a subsequent exercise period. From a physical perspective, fatigue can be characterised as decreased power output that leads to impaired physical performance.\textsuperscript{123} For various sports this may be quantified as a slower time to cover a set distance, or a reduced maximal velocity; but for team sports such as basketball, which have both physiological and skill components, the duration and intensity of on-court playing time impact physically and physiologically to decrease physical capacity, and also skill performance. This approach has practical appeal, as it endeavours to quantify the most important attribute in team sports; how the often
unmeasurable mechanistic forms of fatigue mentioned previously impact on a player’s ability to contribute to the requirements of the game, and that of the team. This can be applied in either the short term i.e. a single game, or the longer term such as repeated games in a tournament competition. Therefore, accepting that the true nature of fatigue will be multifaceted, the definition of fatigue within the context of this thesis relates to a decrease in physical performance when assessed by suitable testing protocols.

Fatigue is evident during the second half of a basketball game; although players continue to meet the low intensity demands of play, maximal sprints, repeated efforts and basketball-specific movements can be compromised. In a study of 30 national level players over five games, the total distance covered during play was significantly less in the second half, as was the distance covered by moderate (21% less) and high (20% less) speed running, and the number of jumps (12% less). Although these measures are influenced by the variable nature of team play, corresponding physiological measures of heart rate and blood lactate concentration also decreased substantially in the second half. These findings suggest that players may not maintain the same levels of intensity, or work output on-court as fatigue develops through the course of a game.

The impact of fatigue on skill execution in basketball has received little attention. Intuitively, an increase in physiological fatigue should impact on the execution of a well developed motor skill as fatigue develops in the systems previously mentioned. A recent case study demonstrated that long range jump-shot performance decreased with accumulated fatigue in a basketball specific drill. The results of the study clearly demonstrate changes in the shooting technique, in particular the heights of the shoulder axis and of the wrist both decreased as a consequence of moderate and, in particular, heavy fatigue.

The ability of the leg musculature to generate power can be reduced by 18% three days after a series of repeated vertical jumps. Additionally, there was small but substantial performance decrement of 0.06 s during a 10 x 10 m intermittent sprint running test at two days, with no change at three days. Given that the demands of basketball play require high-
speed intermittent running, and repeated jumps, the compounding effects of these demands may be greater than previously expected during tournament play.

Investigations during tournament play in other team sports indicates significant changes in time-motion characteristics and repeat sprint ability, with evidence of residual fatigue. In field hockey, the percent of total game time spent standing and striding significantly increased, while jogging significantly decreased. These data suggest that when players play three games within four days there are significant changes in time-motion analysis. Given the lack of information available regarding the impact of basketball play on performance, determining the fatigue-related changes in physical performance after several days of basketball play would be advantageous in the preparation of weekly training, conditioning requirements, and for the overall management of player workloads.

2.7. Recovery

Recovery from the demands of competition and training workloads is an important component of basketball programs, as adequate and timely recovery may allow players to resume training activities earlier, or maintain performance in subsequent competition. Recovery strategies used to recover from physical and physiological fatigue can take several forms, from simple stretching routines and nutritional strategies to replenish fuel and electrolyte balances, to structured water-based protocols and compression garments. Water immersion protocols have become popular components of the post-training and competition routines for many team sports, and are emerging research areas within the sport science literature. Compression garments are commercially advertised as a panacea to the delayed onset muscle soreness (DOMS) experienced after unaccustomed exercise, and for the removal of lactate which accumulates during exercise. However these strategies have not been extensively studied outside of controlled laboratory studies using heavy eccentric based protocols.

Few practical studies within the competition environment have been completed determining the effectiveness of these strategies in maintaining or increasing performance.
One study has reported a beneficial impact from using several recovery practices in combination to maintain sprint performance over the first four days of a simulated soccer tournament.\textsuperscript{130} The efficacy of an active warm down for players competing in two soccer games within 72 h revealed that vertical jump, 30-metre acceleration, and repeat sprint ability were maintained compared to a passive control group.\textsuperscript{131} The impact of stretching, pool activity and contrast water therapy were evaluated at two post-game time points following an Australian Football match. The authors found that power and performance measures 48 hours post game were not enhanced by performing immediate post-game recovery compared to next day recovery.\textsuperscript{132} Another study has shown that the use of cold-water immersion and compression garments enhances the clearance rate of muscle damage markers after a single rugby union match.\textsuperscript{133} The effect of cold-water immersion, active recovery, and massage has been investigated after repeated bouts of intermittent cycling separated by 24 hours. An ~4 second benefit was gained equally by all three recovery interventions compared to a passive control group.\textsuperscript{134} While these practices are well established the quest for more effective strategies, in isolation or combination, has prompted the current interest in recovery. However, the efficacy of these practices is likely to improve as scientists investigate various protocols. Within the tournament scenario, and specific to basketball, there has been no research in to the utility of various recovery strategies.

Musculoskeletal soreness occurs after strenuous exercise, this soreness may be related to both metabolic and mechanical insult on muscle microstructure. This pain may be experienced 1-2 days after the exercise bout which may or may not be unaccustomed. Minimising the detrimental effects of this DOMS is a main focus for implementing water-based and compression recovery strategies. The mechanism/s explaining the physiological effect of cold-water immersion, or compression benefiting athletic performance and minimising the limitations of DOMS has yet to be fully explained. There are however several physiological responses which occur during cold-water immersion that may provide some insight.
Functional strength deficiencies have been improved following DOMS-inducing exercise using water-based compared to passive recovery. Myoglobin and creatine kinase have shown to be reduced following cold-water immersion used immediately after intermittent running, and decreasing these muscle damage markers may impact on the amount of oedema experienced with DOMS. A reduction in muscle oedema may be related to the hydrostatic pressure associated with water immersion, as fluid shifts have been shown between interstitial spaces. There is an elevated sympathetic, and decreased parasympathetic activation during exercise; water-based recovery post exercise may aid in neurological recovery by restoring the sympathetic/parasympathetic balance, and neurohormonal activity. A ‘muscle pumping’ effect due to the vasoconstriction and vasodilation following contrast water therapy has been suggested to provide oxygenated blood, and remove metabolic waste, however this remains largely unproven. Reduction in the muscle pain-spasm cycle, decreased muscle stiffness and increased range of motion are also possible explanations as to why athletes feel better after exposure to water-based recovery. All of these possible mechanisms may provide an environment within muscle that allows improved function and force production, allowing athletic performance to be maintained.

2.8. Sport technology
Technological innovation in sport has grown at an exponential rate over the last 10 years. The developments in sport technology have been numerous, from simple aspects of sport shoe development, to artificial turf and the extremes of understanding genetic profiles of elite performance. Within the team sport environment, video technology has been influential in expanding player-coach interaction regarding aspects of the player’s performance. Within basketball the emphasis of video is for reporting game analysis, tactical movements, assessment and monitoring of technical skills, and feedback in training.

Global positioning systems have been miniaturised for ease if use in outdoor team sports. The use of existing orbiting satellites allows the position of an athlete to be determined, and the collection of data at up to five times per second allows the quantification
of distance, velocity and running characteristics. Advancements in micro-electronics and other micro-technologies have made it possible to build small unobtrusive instrumentation for a number of sporting applications. Pedometers, heart rate monitors and bicycle computers are common place and represent some of the earliest technological innovations popular with elite athletes. Today the accelerometer technology of pedometers has evolved to measure force and velocity in all three dimensions, as well as direction of movement and rotational forces. These devices can be attached at any position on an athlete to monitor gross movements, or the movement of individual limbs.144 Accelerometers have been used extensively in the general population setting as a measure of physical activity.145 This application is understandable and worthwhile as accelerometers provide a directly quantifiable and objective measure of the frequency of movements over time. Accelerometers are easy to use and unobtrusive during daily activity in both general and athletic settings. In athletic settings, the use of accelerometers has mainly been in the analysis of gait or segmental movement. This may in part have been due to the size of the technology, or the rudimentary assessment of uni-axial data.

With the availability of this technology comes the mass of data associated with the output, and this may be one of the limiting factors that has not seen accelerometers used extensively in sporting situations. Additionally, the validity and reliability of the accelerometer data from sport has not been assessed, leaving questions as to the utility of the information that is collected. The technology itself may also be under question as to the capacity of the accelerometers to collect data at a frequency that will capture the events of high speed athletic movement. These factors may be why the use of accelerometer technology has not yet been fully embraced by sport scientists. Therefore, investigations of the utility of this information are needed for practitioners interested in quantifying the holistic demands of their sport.

Heart rate monitoring systems have evolved from providing simple beat-min⁻¹ information, to comprehensive feedback of physiological responses based on predictive mathematical algorithms. The use of these emerging technologies provides an opportunity to
investigate the demands of sport from a differing perspective to previous methods, and perhaps reveal novel concepts and information for practitioners. To date there is little information regarding the use of accelerometers in team sport, with one piece of research using a uni-axial accelerometer in boys basketball finding moderate correlations for physical activity with heart rate.\textsuperscript{146} Similarly, there is limited research that integrates the information from both accelerometer and heart rate information. Halsey et al.,\textsuperscript{147} concluded that overall dynamic body activity assessed with tri-axial accelerometers was a good predictor of VO\textsubscript{2}, but not as good as heart rate during treadmill walking and running.

### 2.9. Conclusion and research questions

The aim of any basketball program, and the coaches and support staff within that program, are to present an environment that has the correct physical and physiological stimulation to provide improvement for their players. The prescription of the training within these programs is often based on the previous history and beliefs of the coach, with little scientific involvement. A scientific perspective of the demands of basketball are important on several levels: firstly, understanding the training and competition demands can provide information on the correct training loads to implement during the week to minimise the risk of injury. Secondly, a basketball season does not allow for periodisation of the training program to peak for certain games within the season. Therefore managing player loads allows the team the best possible chance of success as key players remain healthy. Thirdly, understanding the demands of competition allows coaches to manage on-court volume, prescribe appropriate recovery, and design training to replicate game demands, with or without game-specific intensity.

Detailed analysis of the physical demands and physiological response to training and competition, in particular the demands of offensive and defensive components of play, and the compounding effects of tournament competition are required. Utilising emerging wearable-sensor technology may provide coaches with detailed information of the physical movements associated with the various practice components, and how these components relate to the demands of game play. This would allow coaches to structure training in order to
obtain or minimise the correct training response. Once training and competition is complete, advocating recovery strategies to minimise the detrimental aspects of high intensity exercise, and maintain performance is required. Presently, this prescription is at best anecdotal in basketball and in the team sports generally. Sound evidence of the benefits of water-based recovery strategies in a basketball context has not been investigated, and will inform programs of the most appropriate protocols. Longitudinal monitoring of critical performance measures and how athletes respond within- and between-seasons would provide practical insight of the trends for developing players, and provide coaches with contextual information to gauge the rate of development for their players.

The specific research questions addressed in this thesis are:

Are heart rate monitor systems with predictive algorithms for oxygen use and energy expenditure valid and reliable for use in determining the physiological demands of basketball?

Can fatigue in tournament style basketball play be quantified, and does the application of cold-water immersion or compression garments improve, maintain or limit performance in subsequent games?

What is the degree of muscle damage associated with basketball tournament play, and can any damage be alleviated by the use of cold-water immersion or compression garments in an attempt to maintain performance?

The line-drill test is commonly used as a performance test in development programs; can a longitudinal analysis of test data determine within- and between-season trends in player performance?

Can the physical and physiological demands of basketball training and competition be quantified through the use of tri-axial accelerometry, and a validated system (study 1) for predicating oxygen use and energy expenditure?
Chapter 3.
Validation of heart rate monitor-based predictions of oxygen uptake and energy expenditure.

3.1. Introduction

The measurement of oxygen consumption (VO₂) and energy expenditure in the laboratory is well established for individual endurance-type sports such as running, cycling, and rowing. In contrast, the ability to measure or monitor changes in VO₂ specific to a team-based field, or court-based sport is technically difficult. Information on the changes in VO₂ and energy expenditure during play would provide insightful information for coaches and scientists about the metabolic demands of the sport and the adaptations that occur with training. Moreover, the determination of VO₂ in a laboratory is time-consuming in the context of a busy training schedule, and financially challenging to test an entire team.

The accuracy (typical error) of laboratory-based VO₂ systems should be <3%. A comprehensive review of the relevant literature shows that many of these systems, if not calibrated correctly, show error values up to 12%. However the growing awareness of test reliability, along with the guidelines of acceptable tolerances highlights the need for scientists to quantify the level of accuracy in laboratory equipment. Portable metabolic measurement systems have been developed and validated, however these have their limitations, and are generally impractical for team-based sports. Several studies have showed a high degree of error from 2-22% across low and high intensity workloads. Errors in these systems arise from both mechanical and sampling issues, and the inherent biological variability in subjects from test to test.

Heart rate (HR) is a reasonable surrogate measure of VO₂ and energy expenditure given its linear relationship with these parameters at sub-maximal exercise intensities. A correlation coefficient of 0.91 showed that after adjusting for age, gender, body mass and fitness, it is possible to estimate the energy expenditure during physical activity from HR
However, the estimation of VO\textsubscript{2} and energy expenditure from HR values is limited in the team-sport setting, where steady-state conditions are infrequent. The recent development of HR monitoring systems which incorporate algorithm-based predictive software to assess VO\textsubscript{2} and energy expenditure are appealing to many sport practitioners. Heart-rate based monitoring of these variables could be useful in quantifying physiological responses to the training and competitive environment. However the reliability and validity of these systems with highly-trained athletes needs independent evaluation before widespread use.

The Suunto™ personal HR monitoring system includes software for estimation of VO\textsubscript{2} and energy expenditure based on methods developed by Firstbeat Technologies Ltd (Jyväskylä, Finland). Basically, neural networks were constructed for estimation of VO\textsubscript{2} and energy expenditure from R-R heart beat intervals, R-R derived respiration rate, and the on-and-off VO\textsubscript{2} dynamics during various exercise conditions.\textsuperscript{18, 97-98, 156-157} Although the investigators acknowledge the limitations in the accuracy of the predictions when individual values for maximal HR and VO\textsubscript{2} are included, they give little information on the validity against pulmonary gas exchange values or correction factors to account for variation in these estimates. Recently, evaluation of the Firstbeat software in predicting VO\textsubscript{2} and energy expenditure across 25 low– to high-intensity daily tasks revealed a mean under-prediction of 1.5 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} and 27 kcal (113 kJ).\textsuperscript{158} No substantial difference was observed in the low intensity tasks, with the variation increasing to 3.5 and 2.2 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} for the moderate-, and high-intensity tasks, respectively. Although informative, whether these magnitudes of variation in predictive capacity are maintained for higher-level intensities of exercise commonly undertaken by elite athletes is unclear. The purpose of this study was to determine the validity and variation of the Suunto™ HR system compared to pulmonary gas exchange values for the estimation of VO\textsubscript{2} and energy expenditure during sub-maximal, and maximal intensity treadmill running in well-trained runners.
3.2. Methods

3.2.1. Experimental approach to the problem
Each participant completed a two-component (i.e., sub-maximal, and ii. maximal) treadmill running test where pulmonary gas exchange was measured and recorded over 30-second intervals throughout the testing period. We used an open-circuit, computerized metabolic cart comprising Ametek O₂ and CO₂ analysers as described previously.¹⁵⁹ The analysers were calibrated with three α gases of known concentration (BOC Gases Australia) before each test. Calibration was accepted at ±0.03% of the target value. The accuracy of the analysis system was compared to an automated VO₂ calibrator for open-circuit indirect calorimetric systems.¹⁶⁰ Estimated VO₂ values were within ±5% as specified by guidelines of the National Sport Science Quality Assurance Program (Australian Sports Commission, Canberra, Australia). During the test, each participant wore a commercially available HR monitoring device (Suunto™, Vantaa, Finland) and HR was recorded continuously during the entire testing period. The peak HR was recorded every 30 seconds during each component. Validity of the Suunto™ software to estimate VO₂ and energy expenditure was compared against the criterion values of the metabolic cart. Three levels of the Suunto™ software analysis were evaluated. The first level of analysis required the input of the participant’s basic personal information (BI) of age, body mass, height, gender, and level of activity. The software then predicted maximal HR and VO₂. The second level of analysis used the same basic personal information with the addition of the maximal HR (BI₀hr) as determined from the treadmill test. The third level of analysis added the laboratory-measured VO₂peak to the maximal HR and basic personal information (BI₀hr+). In total, the HR recordings for each participant’s test were analysed three times to determine any improvement in accuracy for the software estimations. Estimations of energy expenditure were calculated from equations and tables of energy equivalents for the oxidation of fat-carbohydrate mixtures as described previously.¹⁶¹
### 3.2.1. Subjects

Ten male (age, 29.8 ± 4.3 (mean ± SD) y; body mass 70.0 ± 7.7 kg; height 1.79 ± 0.51 m; VO₂peak 65.9 ± 9.7 ml·kg⁻¹·min⁻¹; maximum heart rate 189 ± 8 beat·min⁻¹) and seven female (25.6 ± 3.6 y; 59.6 ± 2.9 kg; 1.69 ± 0.39 m; 57.0 ± 4.2 ml·kg⁻¹·min⁻¹; 189 ± 11 beat·min⁻¹) well-trained runners, who had been training continuously for the previous six months volunteered to participate in the study. The study was approved by the Ethics Committee of the Australian Institute of Sport, and all subjects were verbally informed of the study requirements and signed an informed consent document prior to commencement.

### 3.2.2. Procedures

Subjects were required to fast overnight prior to performing sub-maximal and maximal treadmill testing (0600 – 0800 h). At the beginning of the test, all subjects were seated passively (semi-supine) on the treadmill for a 5-min period while resting expired gases and HR were recorded. The treadmill protocol included two exercise components i. Sub-maximal; a series of at least five, 4-min exercise intervals (stages) performed below the individual’s gas exchange threshold, and ii. Maximal; a short incremental run to exhaustion. Depending on the participant’s running ability, the first stage of the sub-maximal component commenced at a pre-determined running speed (range 9-15 km·hr⁻¹), at a set gradient of 1%. The pre-determined running speed was set at an intensity that would allow the subject to complete at least five 4-min sub-maximal stages of increasing intensity, and reach a blood lactate concentration of 4 mmol·L⁻¹. A 1-min rest period was taken between stages for collection of a capillary blood sample. Running speed for each subsequent stage increased by 1 km·h⁻¹. At the completion of the sub-maximal component, subjects kept the mouthpiece in place, and remained seated on the treadmill while expired gases were collected for a further 10 min. After the 10-min period, subjects were allowed 1 min to prepare for the maximal component of the test, which consisted of 1-min stages commencing at the same initial running speed as the sub-maximal component. Running speed was increased by 1 km·h⁻¹ every min until volitional fatigue, with the treadmill gradient held constant at 1% for the duration of the test.
Following the maximal component of the test, subjects remained seated with the mouthpiece in place for another 10 min. Data from the last 60 seconds of each of the 4-min sub-maximal stages was used to determine the associated steady state O₂ consumption, and VO₂peak was calculated from the highest value recorded during any 60 seconds of the maximal running component.

3.2.3. Statistical analyses
Simple descriptive statistics are reported as mean and standard deviation (s). Raw values for VO₂ and energy expenditure from the metabolic cart and Suunto™ were log-transformed to account for any non-uniformity of effects and error. Validity was expressed as the standard error of the estimate (SEE) and the coefficient of variation (CV). Reliability was determined from eight subjects who completed a re-test within 7 d of their initial test; the results expressed as the typical error (TE) and CV. Precision of estimation was indicated with 90% confidence limits where applicable. Bias between the practical and criterion measures was assessed by linear regression. The correlation between the criterion and predicted measurements were calculated with a Pearson correlation coefficient and expressed as an r value. The criteria for interpreting the magnitude of correlation were: r<0.1, trivial, r=0.1-0.3, small, r=0.3-0.5, moderate, and r>0.5 large. The smallest worthwhile change in an outcome measurement was established with a small effect size (0.2 x between subject SD) as described previously.162

3.3. Results
The validity of the predicted VO₂ measurements from the Suunto™ system expressed with 90% confidence limits are shown in Table 3.1. The validity of the VO₂ and energy expenditure values predicted by the Suunto™ system improved across the three levels of analysis with the sequential addition of the measured physiological information. There was little difference between the VO₂ estimates for BI, BI_hr, and BI_hr+v and the corresponding %CV. The degree of bias compared with the criterion VO₂ showed an underestimation by the
Suunto™ system, with the difference improving from -10.9% for BI, -3.9% for BIhr, to -0.4% for BIhr+v.
Table 3.1. Standard error and coefficient of variation in VO\textsubscript{2} measures across three levels of analysis within the Suunto™ software compared to the criterion measures from the metabolic cart. BI represents estimations based on the use of basic personal information only; BI\textsubscript{hr} measures are based on the inclusion of correct (measured) individual maximal heart rate to BI; BI\textsubscript{hr+v} measures are based on the addition of the correct (measured) VO\textsubscript{2} values to BI\textsubscript{hr}. CL = 90% Confidence limits; SWC = Smallest worthwhile change (calculated as 0.2 x between participant SD).

<table>
<thead>
<tr>
<th>BI</th>
<th>Estimate</th>
<th>Lower CL</th>
<th>Upper CL</th>
<th>Pearson r</th>
<th>Lower CL</th>
<th>Upper CL</th>
<th>Pearson r</th>
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<td></td>
<td></td>
<td>2.6</td>
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<tr>
<td></td>
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<td>-4.9</td>
<td>-10.9%</td>
<td>-13.1</td>
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<td>Typical error</td>
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<td>1.4%</td>
<td>1.1</td>
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<td>SWC</td>
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<th>Pearson r</th>
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<td>2.8</td>
<td>2.3</td>
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<td>Mean bias</td>
<td>-2.5</td>
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<td>-6.0</td>
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<tr>
<th>BI\textsubscript{hr+v}</th>
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<th>Lower CL</th>
<th>Upper CL</th>
<th>Pearson r</th>
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<th>Pearson r</th>
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<td>-0.4%</td>
<td>-3.1</td>
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Table 3.2. Standard error and coefficient of variation in energy expenditure measures across three levels of analysis within the Suunto™ software compared to the criterion measures of the metabolic cart. BI represents estimations based on the use of basic personal information only; BIhr measures are based on the inclusion of correct (measured) individual maximal heart rate to BI; BIhr+v measures are based on the addition of the correct (measured) VO2 values to BIhr. CL = 90% Confidence limits; SWC = Smallest worthwhile change (calculated as 0.2 x between measurement SD).

<table>
<thead>
<tr>
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<th>BI</th>
<th>BIhr</th>
<th>BIhr+v</th>
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<tr>
<td></td>
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<td>Coefficient of variation CV (%)</td>
<td>Standard error of estimate (kJ)</td>
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<td></td>
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<td>Upper CL</td>
<td>Pearson r</td>
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<tr>
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<td>5.5</td>
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</tr>
<tr>
<td>Mean bias</td>
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<td>-10.4</td>
<td>-4.6</td>
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<tr>
<td>Typical error</td>
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<td>1.2</td>
<td>2.0</td>
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<tr>
<td>SWC</td>
<td>1.7</td>
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</tbody>
</table>

BI

|                  | Lower CL | Upper CL | Pearson r | Lower CL | Upper CL | Pearson r |
| Estimate         | 6.6      | 5.3      | 8.7       | 0.96     | 12.2%    | 9.8       | 16.5      | 0.94     |
| Mean bias        | -2.7     | -5.2     | -0.2      | -1.6%    | -6.0     | 3.0       |
| Typical error    | 2.7      | 2.2      | 3.6       | 4.3%     | 3.4      | 5.9       |
| SWC              | 1.7      |          |           |          |          |           |          |          |           |

BIhr

|                  | Lower CL | Upper CL | Pearson r | Lower CL | Upper CL | Pearson r |
| Estimate         | 6.1      | 4.9      | 8.1       | 0.96     | 12.7%    | 10.1      | 17.1      | 0.94     |
| Mean bias        | -0.2     | -2.8     | 2.3       | -2.1%    | -2.4     | 6.9       |
| Typical error    | 1.4      | 1.1      | 1.9       | 2.3%     | 1.8      | 3.2       |
| SWC              | 1.7      |          |           |          |          |           |          |          |           |
The validity of the predicted energy expenditure measurements from the Suunto™ system are shown in Table 3.2. Values of energy expenditure generated by the software were also underestimated in comparison with criterion gas analysis. The mean error of the estimated energy expenditure, compared to the criterion gas measure, showed small improvements from BI to BIhr and BIhr+v with corresponding %CV of 13.6, 12.2 and 12.7% respectively. The degree of bias compared with the criterion showed an improvement in the underestimation over the three levels of analysis.

The reliability of the Suunto™ system for VO2 expressed as the TE is shown in Table 3.1. Small improvements in TE were seen across the three levels of analysis of BI, BIhr, and BIhr+v, with TE values of 0.64, 0.72 and 0.57 ml·kg⁻¹·min⁻¹ respectively, and corresponding %CV of 1.4, 1.8 and 1.3. For energy expenditure, there were small improvements in the TE values of 1.49, 2.70, 1.38 kJ for BI, BIhr, and BIhr+v, with little difference in the corresponding %CV values of 2.3, 4.3, and 2.3.
Figure 3.1. VO₂ comparisons for Gas analysis (squares) and Suunto™ software (pyramids). The top panel (BI) represents basic information of age, weight, gender and body mass. The middle panel (BIhr) represents the addition of the measured maximal heart rate to basic personal information. The bottom panel (BIhr+v) represents the inclusion of the measured maximal heart rate and VO₂. Error bars are SD. Software predictions for VO₂ are underestimated across all running speeds when only basic information is included.
Figure 3.2. Energy expenditure (kJ) comparisons for Gas analysis (squares) and Suunto™ software (pyramids). The top panel (BI) represents basic information of age, weight, gender and body mass. The middle panel (BI_{hr}) represents the addition of the measured maximal heart rate to basic personal information. The bottom panel (BI_{hr+v}) represents the inclusion of the measured maximal heart rate and VO₂. Error bars are SD.
3.4. Discussion

Providing key physiological information on VO\textsubscript{2} and energy expenditure has great appeal for practitioners monitoring long term changes in athletes. This study has shown that during sub-maximal- and maximal-intensity treadmill running, the estimates of VO\textsubscript{2} from the Suunto\textsuperscript{TM} heart rate system typically vary by \textasciitilde 6\% in comparison with criterion measures of a calibrated expired gas analysis system. This relative inaccuracy can be improved when known (measured) maximal values of HR and VO\textsubscript{2} are included into the software analysis. However, even with the addition of measured HR and VO\textsubscript{2} values the level of error is inferior to laboratory-based methods. Estimates derived via the Suunto\textsuperscript{TM} system are therefore not directly interchangeable with those from laboratory-based analysis systems. Nevertheless, the Suunto\textsuperscript{TM} system should be useful for identifying moderate or large changes in oxygen demand and energy expenditure in field settings.

The smallest worthwhile change concept is useful assessing the practical or clinical significance of effects in a sports setting.\textsuperscript{162} Quantifying the test re-test reliability of a performance test, or measurement tool generates the typical error. The typical error permits the utility of a test to be interpreted via the signal:noise ratio. Where the typical error (noise) is less than the smallest worthwhile change (signal), then the ability of the tool to detect worthwhile change is good. Conversely if the typical error is substantially greater than the smallest worthwhile change, a researcher or practitioner is less confident in detecting worthwhile changes in the laboratory or field. On this basis, given a typical error of \textasciitilde 0.6 ml\cdot kg\textsuperscript{-1}\cdot min\textsuperscript{-1} and a smallest worthwhile change of \textasciitilde 2.3 ml\cdot kg\textsuperscript{-1}\cdot min\textsuperscript{-1}, it follows that the Suunto\textsuperscript{TM} system is useful for identifying moderate or large changes in estimated VO\textsubscript{2}. However, the margin of error is too large for a practitioner to be confident of detecting subtle (but worthwhile) changes observed in a highly-trained athlete during serial monitoring. Similarly, the typical error of \textasciitilde 2.1 kJ and smallest worthwhile change of \textasciitilde 1.7 kJ for energy expenditure indicate that the system is not as useful in predicating energy expenditure.
In a team-based situation, the Suunto™ system may be adequate for assessing the moderate to large changes in within-player fitness measures taken at pre-season, through to competition and off-season periods. Substantial changes in VO₂ have been observed during these training phases in various team sports. The system should also have utility in assessing the physiological responses, and categorizing the energy demands of various field (or court) training sessions. Distinguishing low-, moderate- and high-intensity training drills is useful information for conditioning coaches in team-based settings, as it allows training to be modified according to the accumulated load and intensity experienced during a series of drills. The Suunto™ system has acceptable reliability, which allows practitioners to compare drills or sessions, that have the same temporal and training characteristics, for differences in intensity and physiological demand. The system may also have utility in monitoring the long-term development of the aerobic capacity of junior athletes as they progress to senior levels, and for injured players undertaking rehabilitation programs. Given the limited amount of technology available for use in the field for team sports, the Suunto™ system appears to be an advanced method of quantifying activity compared to current practices.

The utility of the Suunto™ system can be improved by providing additional individual athlete inputs to the software prior to estimation of VO₂ and energy expenditure values. However practitioners need to account for the amount of bias in the estimates. At the basic personal information level, there is substantial uncertainty (up to 10%) in the precision of the estimates of VO₂ and energy expenditure. The large amount of bias associated with the basic level decreases the confidence in the results, but as the bias improves across the additional levels, the results have a higher degree of utility. Presumably the error associated with the basic level relates to the quality and quantity of the subjects in the original studies which the algorithms are based on. The use of a more homogenous subject group, who were highly trained, may decrease the amount of error. The outcomes from the subsequent levels of analysis highlight the close relationship between HR and VO₂: the prediction becomes more agreeable with the criterion measure when the measured values of these variables are
included. There is only minimal improvement with the addition of the measured VO₂ values (Figure 3.1). Given that the software only requires a single figure for maximal values of HR and VO₂, determined at the conclusion of the maximal test, it is of interest that the software is able to make relatively accurate predictions of sub-maximal VO₂ values across several running speeds.

Our estimates for VO₂ at higher intensity running are in agreement with previous reports of VO₂ for ‘high-intensity’ daily tasks.¹⁵⁸ We observed that the values for higher intensity running are underestimated by ~2 ml·kg⁻¹·min⁻¹. In general settings, this margin of error would be acceptable as the broad categorization of the energy cost for daily tasks may not require the precision of laboratory-based measures, and would allow practitioners involved with energy balance to make suitable dietary or activity-related decisions. A moderate degree of accuracy may be acceptable for those practitioners and researchers who are interested in the demands of lower level activities or daily living activities. However, given that the Suunto™ system is marketed as a sports training tool, the benefit for higher level recreational-, and elite-athletes is somewhat limited for assessing small, serial changes in physiological measures during a training season.

Energy expenditure in the current study was under-estimated during the sub-maximal component of the treadmill test across all levels of analysis. Although the standard error estimates of energy expenditure showed large improvements over the three levels of analysis, the degree of bias did not improve, showing an underestimation against the criterion measure. Similarly the CV did not change substantially with the inclusion of all measured variables (Figure 3.2). This finding demonstrates the (in)effectiveness of the algorithms when all measured information is included; the large variation at the basic level of assessment has implications for those using the system in the absence of measured maximal values.

During the maximal stage of the test, estimations of energy expenditure were over-estimated at the initial running speeds. One possible explanation for this finding may be that the HR was slightly elevated as a response to the previous sub-maximal component. We
observed an elevated HR of ~5 beat·min⁻¹ (3%) between the first four stages of the maximal component compared to the corresponding stages (i.e., same speeds) of the sub-maximal component. Although we stipulated a 10-min rest period between the sub-maximal and maximal components of the test, this was insufficient to re-establish a resting HR. Even though subjects were permitted to drink *ad libitum* between stages, elevated HR may reflect cardiac drift associated with dehydration¹⁶⁹ or an altered autonomic tone¹⁷⁰ carried over from the previous sub-maximal component. These ancillary elevations in HR are a limitation to the Suunto™ system, as misleading estimations of energy expenditure could be made from results obtained from HR not essentially associated with the underlying exercise demand.

### 3.5. Practical applications

The Suunto™ heart rate monitoring system is useful for field-based estimations of VO₂ and to a lesser extent, energy expenditure. However, the Suunto™ heart rate monitoring system lacks the precision needed to be a viable alternative to a calibrated metabolic cart in the laboratory setting. Although the system shows a high degree of reliability in a test re-test situation with a typical error of ~1.5%, the magnitude of error shown in this study of ~6% compared to an accurate metabolic cart is outside the acceptable limits of <3% for quantifying small changes or differences in energy demand. The estimation of energy expenditure appears more problematic with error values of ~13%. The system may have some utility in field-based assessments of gross changes in aerobic capacity, or assessing the energy demands of a training/competition session, as a practitioner can be assured of the accuracy between sessions. Although the measures provided by the Suunto™ software are underestimated in comparison with criterion measures of HR and energy expenditure, these predictions are certainly no worse than information reported for portable VO₂ systems. The Suunto™ system appears suitable for assessing energy balance estimations in daily tasks: however practitioners should be aware of the bias associated with the software and account for this in their reporting and exercise programming. The ease of use of the system, with telemetry functionality,
facilitates immediate feedback of changes in both VO$_2$ and energy expenditure, which should provide new insight into field-based assessments.
Chapter 4.

The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball.

4.1. Introduction

National and international basketball tournaments usually consist of several games played on consecutive days. Each game places high physical demands on players as they experience repeated moderate and rapid accelerations and decelerations,\textsuperscript{12, 37} explosive jumps,\textsuperscript{37} and muscle damage from eccentric loading\textsuperscript{171} or contact trauma. Players must be fit enough to limit the impact of muscular and physiological fatigue, and recover adequately to compete in the next game. Limited time for recovery between games can have a negative effect on performance, while increasing the recovery time between games can improve a team’s score.\textsuperscript{172}

Only one published study has examined muscular and physiological fatigue during national level basketball competition. The distance covered in a single game by moderate (21\%) and high (20\%) speed running, and the number of jumps (12\%), decreased markedly during the second half, as did heart rate and blood lactate concentration.\textsuperscript{37} Although players may not maintain the same levels of intensity as fatigue develops during a single game, the magnitude of cumulative fatigue after several games on physical performance has not been examined in the scientific literature. Similarly the most effective recovery strategies to alleviate any associated performance decrements are unclear. The lack of scientific investigation in physical performance and recovery with multi-day tournament play is surprising given that the majority of national and international competitions use this format.

Evidence of performance decrements in other sports using a tournament competition format is sparse. Elite male field hockey players exhibited a significant degree of residual
fatigue, and decrements in striding and repeat effort running during a three day tournament. The ability of the leg musculature to generate power can be reduced after intense repeated exercise. Explosive power was reduced for at least three days after a series of repeated vertical jumps along with intermittent sprint running which was significantly reduced at two days, and still suppressed after three days. These activities are common movement characteristics in basketball, but it is unknown whether these demands compromise following performances during a basketball tournament.

Popular and current recovery strategies have been reviewed previously. The simplest recovery strategies currently used during basketball competitions are re-establishing hydration levels, refuelling of energy stores with carbohydrate diets, and static stretches of the exercised muscle groups. Timely and adequate fluid and carbohydrate ingestion post exercise is now accepted as standard practice in elite sport. Static stretching post-exercise is recommended as a preventative measure for delayed onset muscle soreness, and improved sit-and-reach range of motion through dispersion of oedema or tension reduction of the musculo-tendon unit. However there is no information examining the benefits of stretching to physical performance measures in a tournament setting, or if stretching is more or less beneficial than newer compression and water immersion strategies.

Cold-water immersion and compression garments are popular methods of recovery. Much of the research in this area has been undertaken with heavy eccentric unaccustomed exercise, with little investigation in sport specific settings. Contrast water therapy, which combines alternating cold and warm water exposure, enhanced the clearance rate of creatine kinase after a single rugby union match compared to passive recovery. The effect of cold-water immersion, active recovery, and massage after repeated bouts of intermittent cycling separated by 24 h was similar. Apart from the work of Flannagan & Merrick, the remainder of the recovery research has examined performances immediately upon completion of exercise, or in a single exposure at a designated time point after exercise. The impact of multiple rather than single exposures in a tournament setting is unknown.
Compression garments reportedly provide relief from soreness, swelling, recovery of force production, and enhanced vertical jumping power with repeated jumps. Subjects wearing a compression arm sleeve had a smaller elevation in creatine kinase (CK) for up to 5 days after 2 sets of 50 arm curls. Wearing graduated full leg compression stockings during cycling exercise and recovery decreased blood lactate concentration compared to wearing the garments in exercise only, or not at all. The use of full leg compression garments for 12 h after a single rugby match enhanced CK clearance compared to passive recovery, but was not different to active recovery or cold-water immersion. Conversely, the use of compression garments showed no benefit under fatigue conditions during concentric isokinetic force production, or repeat sprint performance. Given the lower body demands of running and jumping in basketball it seems plausible that lower body compression might be useful in aiding recovery and performance, but no previous studies have specifically addressed this question.

These recovery strategies are often used by team sports in an ad-hoc nature with little scientific evidence on the mechanisms and outcomes available to support their implementation. Given the lack of information available regarding the impact of basketball play on physical performance, the aim of this study was to determine the fatigue-related changes after several days of basketball play, and to compare the effectiveness of a standard, cold-water immersion, and compression recovery interventions to minimise any identified decrements in physical performance.

4.2. Methods

4.2.1. Players

Players were twenty nine male (19.1 ± 2.1 y, 1.84 ± 0.34 m, 88.5 ± 14.7 kg, Σ7 skinfolds 68.9 ± 32.3 mm) basketball players competing regularly in state level competition. This study was conducted late in the pre-season phase as players were preparing for the start of the upcoming season, and had completed several weeks of specific pre-season training. Typical training of
the players compromised 3-4 full team practices (90-120 mins each), 1-2 individual shooting and skill sessions (30-45 mins each), for a total training load of ~8-10 hour per week, thus providing adequate specific preparation for the games.

4.2.2. Experimental design
The study involved a randomised controlled trial investigating the impact of successive days of basketball play. All players were asked to volunteer for, and participate in a three day mini-tournament involving one full 48 minute game per day. Preceding the tournament, players were provided with written and verbal information on the objectives of the study, and completed an informed consent document. The study was approved by the Australian Institute of Sport Ethics Committee and the Griffith University Human Research Ethics Committee.

4.2.3. Experimental procedures
In the week prior to the tournament, all participating players completed the following tests to determine baseline physical performance levels: 20 m acceleration, basketball line-drill, YoYo Level 1 intermittent recovery test, vertical jump, a basketball-specific agility test, and the sit and reach flexibility test. Players were then matched for positional and anthropometric characteristics and assigned to one of three treatment groups as follows:

4.2.3.1 Control (carbohydrate + stretching) (n=9)
All players were directed through a standardised program of 10 stretches completed twice bilaterally for 15 s - kg⁻¹ BM) snack providing sweets, a carbohydrate bar (Powerbar™), and 600 ml of fluid in a sports drink (Gatorade™). Carbohydrate replacement could have taken several forms, but this method was simplistic for standardisation and delivery. From our experience and observations, we considered this to be ‘typical’ minimum post-game practice for basketball that would not impact on performance, and constituted the control group for this study.
4.2.3.2 Cold water immersion (n=10)
Following the standard post-game recovery (control), participants in the cold-water group immersed their entire body, to the mesosternale level in a plunge pool (11°C) for 5 x 1 minute intervals. Between each immersion, players rested passively in ambient air (~23°C) for two minutes.

4.2.3.3 Compression (n=10)
Following the standard post-game recovery (control), participants in the compression group showered and then put on commercially produced, full length lower limb compression garments (LineBreak™, Sydney, Australia (18 mmHg)) for the post-game and overnight period (a total exposure of ~18 hrs). Both control and compression groups rested passively for 15 minutes while the cold-water immersion completed their treatment.

At the same time each morning during the tournament (~0800-0900 h), the players completed daily performance and well-being tests including mid-thigh and mid-calf girth measurements, body mass in playing shorts only, to a precision of 10g, visual analogue scale for leg soreness, with descriptors ranging from 1-'Normal’ to ‘10-Extremely sore’. A general fatigue scale with descriptors ranging from 1-'Not at all’ to ‘10-Extremely tired’, and the vertical jump test were also completed. Players then prepared for and completed their daily competition game (either 1200 or 1400 h, 23.2 ± 1.7°C) in accordance with the normal team arrangements under the direction of the team coach. Within the confines of competition, coaches were asked to provide equal game time between players to ensure similar workload exposure across games. Following the game, all participants were towelled dry, rested supine for 10 minutes and then re-assessed for body mass, visual analogue scale, mid-thigh, and mid-calf girth before completing the predetermined post-game carbohydrate+stretching program. Cold-water immersion and compression groups then performed their respective recovery intervention. The pre-tournament tests were repeated (excluding the YoYo intermittent recovery test) on the morning of the fourth day to assess any performance decrement arising from the competition period.
4.2.3.4 Nutritional control

The carbohydrate content of all foods and fluids was provided in the form of 30 g ‘blocks’. Each player was instructed on the number of blocks required for each meal and snack to ensure the amount and timing of carbohydrate was replicated on each day of the study period to achieve a consistent daily intake of 8 kg\(^1\). A ready reckoner representing menu items as carbohydrate blocks was provided, along with a Food Diary to record intake throughout the study period. Analysis was performed using FoodWorks Professional Edition, Version 3.01, © 1998-2005, Xyris Software, Australia.

4.2.4. Statistical analysis

Simple descriptive statistics are reported as mean ± standard deviation (mean ± SD). The modelling of data involved precision of estimation of changes in the performance and daily monitoring tests using 90% confidence limits. To determine changes between pre- and post-tournament testing of the three treatment groups, mean effects of the recovery treatments were estimated using a mixed model analysis with mean cumulative game time as a covariate. Each change score was expressed as a percentage of the pre-tournament test score by analysing log-transformed values. The exception for this was Sit & Reach and General Fatigue results which are shown in raw units of measurement (mean ± SD). Effects were characterised for their practical (clinical) significance rather than simple interpretations of statistical significance and hypothesis testing. Magnitudes of effect sizes were assessed using the criteria of: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large and >2.0 very large. A substantial performance change was accepted when there was >75% likelihood that the true value of the standardized mean difference was greater than the smallest worthwhile (substantial) change.\(^{185}\) The smallest worthwhile change in performance from test to test was established as a ‘small’ effect size (0.2 x between-subject SD) according to methods outlined previously.\(^{185}\) Mixed modelling was performed with Proc Mixed SAS statistical software (Version 8.2; SAS, Cary, North Carolina, USA).
4.2.4.1 Game time

We were interested to see the effect of additional game time on the level of fatigue in performance tests and the effectiveness of recovery interventions. The effect of additional game time was modelled as 2 standard deviations of the mean game time for all players across all games, and shown as change (%), ±90% Confidence limits. Mean cumulative game time (min:s) for all players was 23:13 ± 4:13 per game. Mean cumulative game time for cold-water immersion, compression and control groups was 20:33 ± 0:28; 23:09 ± 3:42; and 25:09 ± 0:09 respectively.

4.3 Results

4.3.1 Pre tournament performance

The pre tournament performance test results for all participating players (mean ± SD), along with the mean values for each positional group are shown in Table 4.1.

<table>
<thead>
<tr>
<th></th>
<th>ALL (n=29)</th>
<th>Guard (n=14)</th>
<th>Forward (n=11)</th>
<th>Centre (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-drill (s)</td>
<td>27.5 ± 1.2</td>
<td>26.9 ± 0.9</td>
<td>27.9 ± 1.4</td>
<td>27.6 ± 1.4</td>
</tr>
<tr>
<td>20m acceleration (s)</td>
<td>3.09 ± 0.10</td>
<td>3.04 ± 0.07</td>
<td>3.13 ± 0.13</td>
<td>3.10 ± 0.10</td>
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<tr>
<td>Agility (s)</td>
<td>6.5 ± 0.2</td>
<td>6.4 ± 0.2</td>
<td>6.6 ± 0.2</td>
<td>6.6 ± 0.2</td>
</tr>
<tr>
<td>Vertical Jump (cm)</td>
<td>61.9 ± 14.6</td>
<td>61.3 ± 19.9</td>
<td>61.2 ± 7.5</td>
<td>65.3 ± 9.0</td>
</tr>
<tr>
<td>Sit &amp; reach (cm)</td>
<td>10.7 ± 8.4</td>
<td>11.1 ± 8.9</td>
<td>12.0 ± 7.7</td>
<td>8.5 ± 9.3</td>
</tr>
<tr>
<td>YoYo Level 1 (metres)</td>
<td>1592 ± 629</td>
<td>1807 ± 701</td>
<td>1372 ± 537</td>
<td>1500 ± 528</td>
</tr>
</tbody>
</table>

4.3.2 Evidence of accumulated fatigue

The absolute pre and post tournament test scores, along with the associated change (%), are shown in Table 4.2. Substantial cumulative fatigue from three consecutive days of basketball play was evident in several performance measures and elevations in the subjective rating of general fatigue. There were small impairments in line-drill ability which decreased by 0.5 ± 1.8 second (mean ± 90% Confidence limits); a moderate decrement in 20m acceleration of
0.04 ± 1.3 s; a large – very large decrement in agility of 0.1 ± 1.2 s. Sit & reach ability decreased by 5.4 ± 4.0 cm and general fatigue had a very large increase of 2.2 ± 1.5 arbitrary units (scale 1-10).
Table 4.2. The effect of different recovery interventions for pre–post tournament performance tests (mean ± SD), with the change (%) and the associated ± SD of the change score. The change values have been adjusted to account for the mean cumulative game time across all players. Comparisons between treatments are shown as %, ±90%CL. SWC = smallest worthwhile performance change (calculated as 0.2 x between-subject SD). Pre and post performance values are in seconds for Line-drill, Speed and agility; centimetres for V Jump and Sit & Reach; arbitrary units for General Fatigue. * indicates that the change score is in the specified units of measurement, not a %. A negative value in a speed related test indicates that the change is faster, while a negative value for a test measured in units indicates a decrease in performance. CWI = Cold-water immersion; COM = Compression; CON = Carbohydrate+Stretching(Control).

<table>
<thead>
<tr>
<th></th>
<th>CWI (%)</th>
<th>Pre</th>
<th>Post</th>
<th>Change (%)</th>
<th>Pre</th>
<th>Post</th>
<th>Change (%)</th>
<th>Pre</th>
<th>Post</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-drill</td>
<td>0.76</td>
<td>27.42 ± 1.40</td>
<td>27.27 ± 1.04</td>
<td>-1.4 ± 1.7</td>
<td>27.52 ± 0.71</td>
<td>27.05 ± 0.57</td>
<td>-1.5 ± 1.7</td>
<td>27.15 ± 1.60</td>
<td>27.6 ± 1.15</td>
<td>0.4 ± 1.8</td>
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<tr>
<td>20m acceleration</td>
<td>0.65</td>
<td>3.10 ± 0.13</td>
<td>3.12 ± 0.11</td>
<td>0.5 ± 1.4</td>
<td>3.06 ± 0.07</td>
<td>3.17 ± 0.10</td>
<td>3.2 ± 1.6</td>
<td>3.09 ± 0.11</td>
<td>3.13 ± 0.12</td>
<td>0.7 ± 1.3</td>
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<tr>
<td>Agility</td>
<td>0.62</td>
<td>6.46 ± 0.24</td>
<td>6.59 ± 0.24</td>
<td>2.0 ± 1.9</td>
<td>6.61 ± 0.23</td>
<td>6.65 ± 0.27</td>
<td>1.4 ± 2.0</td>
<td>6.48 ± 0.25</td>
<td>6.62 ± 0.26</td>
<td>1.6 ± 1.2</td>
</tr>
<tr>
<td>V Jump (cm)</td>
<td>1.44</td>
<td>67.2 ± 8.4</td>
<td>61.6 ± 6.5</td>
<td>-7.2 ± 3.9</td>
<td>63.6 ± 6.6</td>
<td>59.8 ± 8.1</td>
<td>-6.7 ± 11.2</td>
<td>61.1 ± 8.2</td>
<td>58.7 ± 6.7</td>
<td>-2.6 ± 6.6</td>
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<tr>
<td>Sit &amp; Reach (cm)</td>
<td>1.48</td>
<td>12.0 ± 10.5</td>
<td>8.6 ± 11.5</td>
<td>-4.1 ± 3.2*</td>
<td>11.5 ± 7.9</td>
<td>3.0 ± 9.1</td>
<td>-6.9 ± 4.5*</td>
<td>8.5 ± 6.5</td>
<td>3.2 ± 6.9</td>
<td>-5.4 ± 4.0*</td>
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<tr>
<td>Fatigue (au)</td>
<td>0.27</td>
<td>3.3 ± 1.5</td>
<td>4.5 ± 0.9</td>
<td>1.0 ± 1.6*</td>
<td>3.1 ± 0.9</td>
<td>4.3 ± 1.6</td>
<td>1.1 ± 1.7*</td>
<td>3.6 ± 0.9</td>
<td>5.2 ± 1.6</td>
<td>2.2 ± 1.5*</td>
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<tr>
<td>Muscle soreness</td>
<td>0.33</td>
<td>1.4 ± 0.5</td>
<td>3.3 ± 1.1</td>
<td>1.9 ± 0.7*</td>
<td>1.4 ± 0.5</td>
<td>3.2 ± 1.3</td>
<td>1.8 ± 0.8*</td>
<td>1.6 ± 0.5</td>
<td>4.3 ± 1.8</td>
<td>2.7 ± 1.4*</td>
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</table>

Comparisons between interventions

<table>
<thead>
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<th>COM-CON</th>
<th>CWI-CON</th>
<th>CWI-COM</th>
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</thead>
<tbody>
<tr>
<td>Line-drill</td>
<td>-1.8, ±1.9</td>
<td>-1.8, ±2.1</td>
<td>0.0, ±2.1</td>
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<tr>
<td>20m acceleration</td>
<td>2.5, ±1.8</td>
<td>-0.3, ±1.7</td>
<td>-2.7, ±1.9</td>
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<tr>
<td>Agility</td>
<td>0.1, ±2.1</td>
<td>0.4, ±2.4</td>
<td>0.6, ±2.8</td>
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<tr>
<td>V Jump</td>
<td>-4.2, ±9.9</td>
<td>-4.8, ±6.9</td>
<td>-0.6, ±9.8</td>
</tr>
<tr>
<td>Sit &amp; Reach</td>
<td>-1.5, ±7.2*</td>
<td>1.3, ±6.2*</td>
<td>2.8, ±6.6*</td>
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<tr>
<td>Fatigue</td>
<td>-1.1, ±2.0*</td>
<td>-1.2, ±1.9*</td>
<td>-0.1, ±2.0*</td>
</tr>
<tr>
<td>Muscle soreness</td>
<td>-0.9, ±1.5</td>
<td>-0.8, ±1.5</td>
<td>-0.1, ±0.9</td>
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</tbody>
</table>
Table 4.3. The effect of standardised additional (2 SD) game time (%, ±90%CL) and the magnitude of that change (Effect size). Magnitudes of effect sizes are assessed using the criteria of: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large and >2.0 Very large. All results have been adjusted to the mean cumulative game time for treatment groups. SWC = smallest worthwhile performance change (calculated as 0.2 x between-subject SD).* indicates that the change is in the specified units of measurement, not a %. A negative value in a speed related test indicates that the change is faster, while a negative value for a test measured in units indicates a decrease. CWI = Cold-water immersion; COM = Compression; CON = Carbohydrate+Stretching(Control).

<table>
<thead>
<tr>
<th>Line-drill</th>
<th>CWI</th>
<th>Change</th>
<th>Effect size</th>
<th>Descriptor</th>
<th>Change</th>
<th>Effect size</th>
<th>Descriptor</th>
<th>Change</th>
<th>Effect size</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-drill</td>
<td>CWI</td>
<td>SWC(%)</td>
<td>0.76</td>
<td>-0.1, ±5.7</td>
<td>-0.02</td>
<td>Trivial</td>
<td>3.3, ±5.0</td>
<td>0.69</td>
<td>Moderate</td>
<td>2.5, ±2.8</td>
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<tr>
<td>20m acceleration</td>
<td>COM</td>
<td>0.65</td>
<td>-0.7, ±1.4</td>
<td>-0.20</td>
<td>Small</td>
<td>3.5, ±1.6</td>
<td>1.01</td>
<td>Moderate</td>
<td>0.0, ±1.3</td>
<td>0.01</td>
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<tr>
<td>Agility</td>
<td>CON</td>
<td>0.62</td>
<td>1.8, ±6.6</td>
<td>0.49</td>
<td>Small</td>
<td>6.6, ±7.2</td>
<td>1.70</td>
<td>Large</td>
<td>-0.4, ±2.1</td>
<td>-0.12</td>
</tr>
<tr>
<td>V Jump</td>
<td>CWI</td>
<td>1.44</td>
<td>-8.4, ±10.5</td>
<td>-0.68</td>
<td>Moderate</td>
<td>8.9, ±24.6</td>
<td>0.66</td>
<td>Moderate</td>
<td>-2.9, ±10.7</td>
<td>-0.23</td>
</tr>
<tr>
<td>Sit &amp; Reach</td>
<td>COM</td>
<td>1.48</td>
<td>-2.1, ±10.6</td>
<td>-0.44</td>
<td>Small</td>
<td>0.7, ±11.2</td>
<td>-0.75</td>
<td>Moderate</td>
<td>-2.3, ±7.4</td>
<td>-0.58</td>
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<tr>
<td>Fatigue</td>
<td>CON</td>
<td>0.27</td>
<td>0.5, ±3.6*</td>
<td>-0.47</td>
<td>Small</td>
<td>-1.5, ±3.1*</td>
<td>-1.34</td>
<td>Large</td>
<td>0.5, ±3.1*</td>
<td>-0.44</td>
</tr>
<tr>
<td>Muscle soreness</td>
<td>CWI</td>
<td>0.33</td>
<td>-1.4, ±1.5</td>
<td>-2.76</td>
<td>Very large</td>
<td>-0.8, ±1.9</td>
<td>-1.64</td>
<td>large</td>
<td>0.4, ±2.3</td>
<td>0.73</td>
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<tr>
<td>Muscle soreness</td>
<td>COM</td>
<td>0.33</td>
<td>-1.4, ±1.5</td>
<td>-2.76</td>
<td>Very large</td>
<td>-0.8, ±1.9</td>
<td>-1.64</td>
<td>large</td>
<td>0.4, ±2.3</td>
<td>0.73</td>
</tr>
<tr>
<td>Muscle soreness</td>
<td>CON</td>
<td>0.33</td>
<td>-1.4, ±1.5</td>
<td>-2.76</td>
<td>Very large</td>
<td>-0.8, ±1.9</td>
<td>-1.64</td>
<td>large</td>
<td>0.4, ±2.3</td>
<td>0.73</td>
</tr>
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</table>

Comparisons between interventions

<table>
<thead>
<tr>
<th>Line-drill</th>
<th>CWI-COM</th>
<th>COM-COM</th>
<th>CWI-COM</th>
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</thead>
<tbody>
<tr>
<td>Line-drill</td>
<td>0.8, ±5.0</td>
<td>0.18</td>
<td>-2.5, ±5.7</td>
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<tr>
<td>20m acceleration</td>
<td>3.5, ±4.7</td>
<td>1.00</td>
<td>-0.7, ±5.2</td>
</tr>
<tr>
<td>Agility</td>
<td>7.1, ±7.3</td>
<td>1.82</td>
<td>2.3, ±6.7</td>
</tr>
<tr>
<td>V Jump</td>
<td>12.1, ±26.1</td>
<td>0.89</td>
<td>-5.7, ±12.9</td>
</tr>
<tr>
<td>Sit &amp; Reach</td>
<td>3.0, ±12.3*</td>
<td>-0.16</td>
<td>Trivial</td>
</tr>
<tr>
<td>Fatigue</td>
<td>-1.0, ±3.9*</td>
<td>-0.91</td>
<td>Moderate</td>
</tr>
<tr>
<td>Muscle soreness</td>
<td>-1.2, ±2.8</td>
<td>-2.37</td>
<td>Very large</td>
</tr>
</tbody>
</table>

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4.3.3 Effectiveness of recovery strategies

4.3.3.1 Line-drill
The changes in line-drill performance are shown in Figure 4.1. Comparisons between recovery interventions are shown in Table 4.2. When adjusted to the mean cumulative game time, cold-water immersion and compression had large and equally effective impacts on maintaining line-drill ability, with improvements substantially better for cold-water immersion (1.4% ± 1.7) and compression (1.5% ± 1.7). Over pre – post tournament, the improvement in performance and magnitude of change for cold-water immersion and compression (~0.5 to 1 s) is twice the smallest worthwhile change for the line-drill test, compared to control where the change is smaller, and less than the smallest worthwhile change. There was only a trivial difference between cold-water immersion and compression on changes in line-drill performance.

4.3.3.2 20m acceleration
All treatment groups were slower after three days of consecutive games. Velocity over 20 m was best maintained by cold-water immersion, with only a small 0.02 s decrease. Control had a moderate 0.04 s decrease. Players in the compression group showed a very large decrease of 0.11 s after the tournament. Cold-water immersion was substantially better than compression in minimising the decrement in acceleration over 20 m.

4.3.3.3 Agility
There was no substantial benefit on agility performance from either intervention after 3 days of competition. Large to very large performance decrements in agility were evident after the compression and cold-water immersion interventions respectively.

4.3.3.4 Vertical jump
Mean vertical jump height decreased by ~5 cm after the first game, and ~4 cm after the tournament period for all intervention groups. Compared to control, and adjusted to mean
cumulative game time, cold-water immersion and compression had a large benefit in minimising further decrement in jump performance for the tournament period. There was only a small difference between cold-water immersion and compression in minimising vertical jump fatigue.

4.3.3.5 Sit & reach
All treatment groups exhibited decreased range of movement in the Sit & Reach test in the post tournament testing. Range of movement and hamstring flexibility was best maintained by cold-water immersion with only a 4.1 cm decrement, compared to control and compression which had a 5.4 and 6.9 cm decrease respectively. Compared to the control condition, cold-water immersion was moderately better in maintaining range of movement, while there was a large advantage in cold-water immersion maintaining range of movement compared to compression.

4.3.3.6 Thigh girth
There were only trivial differences in changes in thigh girth between interventions for pre and post game measures, and from pre to post tournament. A similar increase was observed with control (0.7 ± 0.1 cm (1.2%) and compression (0.5 ± 0.2 cm (0.9%) after each game. All girths generally returned to baseline levels the next morning. Although muscle girth increased after the first game with cold-water immersion, there was a trend for cold-water immersion to more effectively minimise thigh girth distension in the post game measure for the remaining games (0.3 ± 0.2 cm (0.5%) compared with compression and control.

4.3.3.7 Calf girth
Similar pre–post game changes were observed for calf girth measures between games and over the tournament period. There were only trivial differences between recovery interventions in minimising calf girth expansion after tournament play.
4.3.3.8 Muscle soreness

Muscle soreness in the legs (1-10 scale) increased substantially over three consecutive days of play. Both cold-water immersion and compression interventions showed substantial benefit in minimising muscle soreness, ~2-fold less compared to control (Table 4.2). Players indicated that after the first game their legs were ‘uncomfortable’ (3 units), which increased to ‘sore’ (5 units) after the third game. Similarly there was a substantial difference between the pre game measure from day one (1 unit), and the morning measure of day 4 (4 units). Cold-water immersion was very effective in providing transient analgesic effects immediately after exposure. The immediate mean post game muscle soreness rating was ‘somewhat sore’ (4.2 ± 1.4 units; mean ± SD). After the cold-water immersion protocol muscle soreness responses decreased to ‘normal’ (2.0 ± 0.7 units). However soreness on the following morning had rebounded back to ‘uncomfortable’ (3.1 ± 1.2 units).

4.3.3.9 General fatigue

Both recovery interventions showed moderate benefit in minimising fatigue. Self-reported fatigue increased substantially over the three games for players in the control group. In contrast, only a slight increase in fatigue was evident for both cold-water immersion and compression treatments with no difference between groups.
Figure 4.1. The differences in recovery treatment groups for their impact on various performance tests, girth measures and leg muscle soreness from the pre – post tournament period. Error bars are 90% confidence limits. CWI = Cold-water immersion (5 x 1 minute, 11°C), COM = Compression garment, CON = Carbohydrate+stretching (Control).
4.3.3.10 Additional game time

The impact of modelling additional (standardised) game time and the magnitude of the change in the effectiveness of the recovery treatments are shown in Table 4.3. With 8:26 min:s of additional game time under the cold-water immersion treatment, there would be only a trivial change (-0.1, ±5.7%, mean, ±90% Confidence limits) to line-drill performance. However, using the control and compression treatments, performance would decrease by a further 2.5, ±2.8% and 3.3, ±5.0% respectively. For 20m acceleration, cold-water immersion would have a moderate benefit on performance (0.7%, ±1.4%), the compression group would have a very large decrease (3.5, ±1.6%) in performance, and control no change (0.0, ±1.3%). Additional game time with cold-water immersion would have a small impact (1.8, ±6.6%) on agility performance; compression would continue to have large declines (6.6, ±7.2%), while there would be a small benefit for the control group. Cold-water immersion would have a moderate additional benefit (8.4, ±10.6%) on vertical jump performance, with compression having a very large (8.9, ±24.6%) reversal in ability, with no substantial change for the control group. The effects of additional game time on range of movement and hamstring flexibility with cold-water immersion (2.1, ±10.6%) would have a small benefit; a moderate benefit from compression (0.7, ±11.2%) and a small decrease (2.3, ±7.4%) with control.

4.3.3.11 Carbohydrate intake

Mean daily intake over the study period was 7.7 ± kg^{-1} day. Intake across meals and days was consistent between control – cold-water immersion and cold-water immersion - compression, there was a moderate (1.0, ±1.1%) increase in carbohydrate intake for control (1.2 ± kg^{-1} day) compared to compression.

4.3.3.12 Hydration

Average water intake per game for all players was 1.8 ± 0.96 L. Relative to actual playing time on court, this equates to 0.80 ± 0.41 L·min^{-1}. There was no difference in the water intake for all games between groups (cold-water immersion: 1.87 ± 0.96 L; compression: 1.86 ± 0.85L; control: 1.84 ± 0.84 L. Average post game body mass change was 0.7 ± 0.0 kg (0.3%)
for cold-water immersion; 0.4 ± 0.1 kg (-0.5%) for compression, and 0.18 ± 0.01 kg (-0.01%) for control.

4.4. Discussion
Repeating high intensity basketball games over several days intuitively creates substantial fatigue and performance decrements, decreasing a team’s competitive ability. We have shown in a well controlled, real-life tournament that cumulative fatigue is evident from the demands experienced after three consecutive days of basketball play. The magnitude of the decrement was small - moderate across various measures of fitness and performance including acceleration, repeat effort line-drill, agility, vertical jump, muscle soreness and flexibility. However these decrements can be attenuated through the use of cold-water immersion recovery with small - moderate benefits accruing after 5 x 1 min exposures at 11 °C. The effectiveness of the cold-water immersion strategy over compression garments and stretching becomes more evident by minimising further performance decrement with additional game participation.

Fatigue associated with basketball may be defined as an inability to maintain the demands of play. Determining the contribution to this fatigue from individual physical, and physiological systems is complex, but it is reasonable to suggest that a functional decline in one or several systems,123 will lead to the loss of playing performance in a following game. In the absence of a recovery strategy, coaches can typically expect players to decrease in line-drill ability by ~0.5 s after three day’s play. In contrast, application of repeat cold-water immersion or compression recovery will enhance performance by ~0.15 - 0.5 s. This magnitude of improvement equates to a large ~1 s (~1.5, ±1.7%) advantage for the player using these techniques, compared to an opponent who is not.

There is little evidence-based support for application of recovery strategies during or after tournament play. Previously, 20 m acceleration in soccer was shown to decrease by 0.02 s second using a cold-water immersion, carbohydrate, hydration and stretching program,130 a magnitude of impairment similar to the current findings. Application of stretching, pool
activity and contrast water therapy after a single Australian Football match, found that performance measures were not enhanced 48 hrs post game. The use of cold-water immersion or compression garments were equally beneficial in assisting the clearance of muscle damage markers compared to passive recovery after a single rugby match. Collectively these findings and the current investigation indicate that recovery practices based on cold-water immersion directly after competition may have greater utility in team sport settings. More controlled and mechanistic research is required to confirm this preliminary conclusion.

The physiological mechanisms accountable for the observed performance effects of the cold-water immersion recovery intervention are speculative within the limitations of the study. Basketball players can experience a significant progressive deterioration in anaerobic power and skill performance with moderate dehydration of 2-4%. As the games in our study were played indoors in mild temperatures (~25°C), and the players were well hydrated, we believe that hypo-hydration was an unlikely reason for the performance decrements. No studies have investigated the impact of glycogen depletion during basketball play. The carbohydrate content of the diet can influence the amount of high intensity exercise performed in multiple sprint sports. Including the immediate post game feedings should have been conducive to maintaining muscle glycogen repletion. If hydration and muscle glycogen levels are stable, the fatigue observed in this tournament setting may be more related to neuromuscular or mechanical factors.

High eccentric loads may result in muscle micro-trauma causing soreness, swelling, stiffness and reduced range of movement lasting several days, particularly when the exercise is unaccustomed. Basketball play presumably creates high eccentric loads during decelerations and jumping, which would not be considered as unaccustomed exercise for the players in the current study. We expected that the game demands would not elicit substantial swelling and stiffness, or reduced range of movement. However, we found a ~1 cm increase
in thigh girth, muscle soreness increased to ~5 on the visual analogue scale, and a reduced sit and reach ability (5.4 cm) after each game in the control condition. Although the initial post game increase in thigh and calf girth may have been due to a transient increase in peripheral blood flow, it is not a complete explanation as for why there is a continual (albeit slight) increase in thigh and calf girth for the control and compression groups as opposed to cold-water immersion, which tends to decrease over the three game period. It may be that these changes are associated with redistribution of exercise induced muscle oedema.

Possible explanations for the beneficial impact of cold-water immersion may be hydrostatic pressure or reduced neuromuscular responses. The cold-water immersion group were immersed vertically in a plunge pool 2.5 m deep; the hydrostatic pressure of this volume of water at a depth of average player height (1.84 m) is ~127 mmHg, and 110 mmHg at a depth of 1.5 m. Cutaneous interstitial pressure increases proportionally to the depth of the immersed body parts. Large fluid shifts from intracellular to interstitial and vascular compartments can also occur with water immersion at 18°C. This pressure may restrict the accumulation of oedema within muscle due to exercise, with the fluid shifts enhancing the clearance of waste substrates due to enhanced diffusion gradients. A reduced perception of fatigue may also come from alterations of peripheral processes associated with muscle contraction. Partial weightlessness and hydrostatic pressure may be inhibitory mechanisms of neuromuscular function, inducing muscle relaxation. This may allow for decreased muscular activity, and with the facilitation of greater waste removal through increased fluid gradients, creates a better homeostatic environment for regeneration to occur.

The impact of water temperature on performance has not been extensively examined in the literature. Studies have shown that cold-water immersion after anaerobic type exercise is not beneficial when a subsequent bout is required in the short term. Cooling muscle post training has also been shown to limit the adaptive response to a training stimulus. These studies all used constant immersion for up to 30 minutes of the lower body or exercised limbs only. As cutaneous interstitial pressure increases proportionally to the depth of immersion,
partial immersion may not create systemic plasma volume and pressure changes associated with fluid shifts. Additionally, these cooling periods are excessive when compared to real-life exercise scenarios. Using cold-water immersion after anaerobic type exercise improved performance when the repeated bout was separated by 24 h.\textsuperscript{134} It may be that an immediate cold-water immersion recovery intervention may limit the initial damaging aspects from inflammatory over-compensation, and when followed by an extended period of normal repair and adaptation maintains, or enhances performance. The immediate cryothermic impact may inhibit the short term neuro-muscular aspects of power development. It remains to be clarified if temperature \textit{per se} plays a critical role after repeated exposures for performance enhancement in team sport or tournament competition.

Previous investigations in exercise settings, and in acute unaccustomed eccentric damage have shown positive outcomes with compression garments.\textsuperscript{128, 180, 194} The previous hydrostatic pressure estimations show that at the lower leg and thigh level, pressures are likely to be substantially greater than the ~18 mmHg reported by the manufacturer (personal communication) for both the compression garments used in this study. In comparison, medical grade compression may be as high as 80 mmHg. The results from the current study show that the use of these commercial compression garments are no better, and in the case of some physical performance tests, are worse than traditional post game activities. It may be that the level of compression is insufficient to have a beneficial impact following normal exercise; however after extreme eccentric exercise, compression garments may be effective when disruption to muscle architecture and swelling are more apparent. Therefore, despite evidence of accumulated fatigue in this tournament scenario, using compression garments for extended periods after competition appears to have little benefit in maintaining or improving performance.

\textbf{4.5. Conclusion}

We have shown that accumulated small to moderate levels of fatigue and physical performance decrements occur after three days of basketball tournament play, can be partially
attenuated when players perform well-targeted post-game recovery interventions. Repeated cold-water immersion provides small - moderate performance gains, being most effective in maintaining line-drill performance and acceleration when compared to compression garments and traditional carbohydrate and stretching practices. A starting player required to play a greater amount of game time during the course of a tournament will benefit from cold-water immersion recovery. Although the use of cold-water immersion would appear more favourable, this strategy may not always be practical. Full leg compression garments appear to have minimal benefit in the majority of the performance tests used here, and provide no performance benefits with increasing game participation time. Future studies should address the potential benefits of combined recovery practices in a dose-response manner, and whether performance benefits via water immersion are temperature or pressure related.
Chapter 5.
Muscle damage, inflammation and recovery interventions during a 3-day basketball tournament.

5.1. Introduction
Basketball is a team sport characterized by numerous high intensity repeated efforts followed by rapid decelerations and eccentric loads in limited space. These demands are compounded by numerous jumps and changes in direction during both offensive and defensive movements, and are likely to be amplified when games are played on consecutive days during tournaments. In comparison to other muscle damage studies, basketball would be considered low volume eccentric exercise. Adaptation to eccentric exercise can occur without significant muscle damage and associated symptoms. In addition, exposure to a small number of non-damaging eccentric contractions appears to provide protection and improve recovery from a subsequent damaging bout. This sequence of events implies that well-trained players may exhibit blunted responses to various serum muscle damage markers after play.

Recovery practices, in particular cold-water immersion (CWI) and use of compression garments (COMP) are now an integral component of post-game activities in high performance team sports. Little information exists on the effectiveness of these recovery strategies, particularly the extent to which they minimize muscle damage or enhance the clearance of waste products. Much of the literature regarding recovery strategies and muscle damage has employed aggressive eccentric loading protocols to induce large amounts of damage. However, in team sports the amount of exercise-related damage may be considerably less than that evoked by controlled eccentric-biased exercise. Recently, a protocol using 3 x 1 minute plunge at 5°C CWI had no impact on serum creatine kinase (CK) concentration, when used as a marker of muscle damage. Similarly, the use of constant CWI at 10°C for 10 minutes following an intermittent exercise protocol had no impact on CK, but reduced serum myoglobin (Mb), another marker of muscle damage. In contrast, the use of contrast water therapy and COMP both independently enhanced the clearance of interstitial...
CK compared with a control treatment after a single rugby match\textsuperscript{183} and serum CK after a repeat sprint trial.\textsuperscript{184} Further research is needed to clarify these conflicting reports.

Muscle damage essentially occurs in two phases. First, mechanical damage to the contractile unit or plasma membrane occurs primarily due to the eccentric component of muscle movement. This insult may initiate metabolic/chemical pathways in the following hours or days creating further damage due to factors such as calcium influx, decreased membrane resistance and free-radical production. These events lead to a generalised inflammatory cascade in response to muscle damage, which involves the release of various cytokines responsible for the initiation and moderation of the inflammatory response. Although serum CK has been used extensively in studies to assess the degree of muscle damage, measurements should be interpreted carefully, as the response to an initial exercise bout can remain elevated for several days. Fatty acid binding protein (FABP) and Mb are found in relatively large amounts in skeletal muscle. Measurement of FABP and Mb may overcome the shortcomings of interpreting post-exercise changes in CK concentration and muscle damage, as values typically peak 30 minutes after exercise and return to baseline $\sim$24 h post exercise,\textsuperscript{201-202} allowing observations of acute changes.

Cytokines play an important role in the inflammatory response to muscle damage and subsequent repair process. Interleukin 6 (IL-6) increases after exercise as a function of exercise intensity and duration.\textsuperscript{203-205} The suggested roles of IL-6 during and following exercise include regulation of carbohydrate utilization, stimulation of the restoration of damaged or depleted muscle proteins, mobilization and activation of neutrophils, and suppression of further muscle damage.\textsuperscript{206} Interleukin 10 (IL-10) plays an important role in containing and resolving the inflammatory process via suppression of pro-inflammatory cytokines.\textsuperscript{207} To date, there is no evidence detailing the concentration of these cytokines following a single basketball game or a series of games over several days or their relationships with traditional markers of muscle damage. The purpose of the study was to examine changes in blood markers of muscle damage and inflammation associated with multi-game basketball
tournament, and determine whether recovery practices have a substantial effect in ameliorating increases in the circulating level of these biomarkers.

5.2. Methods

5.2.1. Participants
Twenty-nine male (19.1 ± 2.1 y, 1.91 ± 0.09 m, 87.9 ± 15.1 kg, Σ7 skinfold 68.9 ± 32.1 mm) basketball players competing regularly in State level competition participated in the study. Players had several weeks of specific pre-season training prior to the tournament study. Players were provided with written and verbal information on the objectives of the study, and completed an informed consent document prior to participation. The study was approved by the associated institutions Human Research Ethics Committees.

5.2.2. Experimental design
The study involved a randomized controlled experimental design of parallel groups, investigating the impact of successive days of basketball play on muscle damage markers CK, Mb and FABP and the cytokines IL-6 and IL-10. We were also interested to determine whether the application of common recovery practices had a substantial impact on the concentration, and clearance rates of these biomarkers after a single game, and over the pre to post-tournament period. All participants were asked to volunteer for, and participate in a three day mini-tournament involving one full 48 minute game per day. Players and groups were matched for positional and physical characteristics and assigned to one of three treatment groups: CHO and stretching (CON, n=9), cold-water immersion (CWI, n=10), and compression garments (COMP, n=10). This allocation ensured that the treatment groups had equal numbers of participating players with similar characteristics, and that players received similar game time. Immediately after each game, all players completed the control condition of CHO replenishment and stretching, regardless of supplementary treatments.
5.2.3. Carbohydrate and stretching (CON)
All players were directed through a standardized post-game recovery program of 10 stretches completed twice bilaterally for 15 s - kg\(^{1}\)BM, containing 600 ml of fluid). These procedures were considered representative of the ‘typical’ minimum post-game practice for basketball and constituted the control group for this study. The players in the CON group did not participate in any further recovery protocols.

5.2.4. Compression (COMP)
Immediately following the standard post-game recovery and after showering, participants in the COMP group were asked to change into full length lower limb compression garments (LineBreak™, Sydney, Australia; ~18 mmHg) for the post-game and overnight period (~18 h). Both CON and COMP groups rested passively for 15 min while the CWI completed their treatment.

5.2.5. Cold-water immersion (CWI)
Following the standard post-game recovery, participants in the CWI group immersed their entire body, to the mesosternale level in a cold-water plunge pool (11°C) for five x 1 minute intervals. Between each immersion, players rested passively in ambient air (~23°C) for two minutes.

5.2.6. Daily measures
At the same time each morning during the tournament (~0800-0900 h), all participants rested supine for 10 minutes before providing an 8 mL blood sample. All samples were collected from a forearm vein using standard venipuncture techniques. Players then completed daily tests including mid-thigh girth measurements, BM, visual analogue scale (VAS) for leg soreness, with descriptors ranging from 1-‘Normal’ to 10-‘Extremely sore’. A general fatigue scale with descriptors ranging from 1-‘Not at all’ to 10-Extremely tired’ was also completed. Players then prepared for and completed their daily game (at either 1200 or 1400 h) in
accordance with the normal team arrangements. Coaches were asked to ensure similar game
time for players across the three competitive games. Following each game, all participants
towelled dry, rested supine for 10 minutes and provided a second 8 mL blood sample.
Participants were then re-assessed for BM, VAS, mid-thigh, and mid-calf girth before
completing the standard post-game recovery program of stretching and CHO consumption.
Participants in the CWI and COMP groups then performed their respective recovery
treatment. A final 8 mL blood sample was collected 6 h after the end of each game.

5.2.7. Nutritional control
Given the reported influence of dietary CHO content on cytokine responses to exercise dietary intake for all players was controlled to achieve a

\[ \text{kg}^{-1} \text{BM} \] kg^{-1}BM. The CHO content of all foods and fluids was provided in the form of 30 g
‘blocks’. Each player was instructed by a member of the research team to ensure the amount
of CHO for each meal was replicated on each day. A self-reported food diary was used to
record all food and fluid consumed throughout the study period. Carbohydrate intake was
Australia. All players were allowed to drink water ad libitum, with CHO sports drinks
excluded during play.

5.2.8. Muscle damage and inflammatory markers
All blood samples were collected directly into a serum separator collection tube (Greiner Bio-
one; Frickenhausen, Germany). Serum was separated by centrifugation at 4000 rpm for 5
minutes and stored frozen at -80°C until analysis. Myoglobin, and the cytokines IL-6 and IL-
10 were measured in serum using an Immulite 1000 solid phase chemiluminescent
immunometric assay system (Diagnostics Products Corporation, CA, USA) and commercially
available assay kits (Diagnostics Products Corporation, CA, USA). CK concentrations were
determined using a Hitachi 911 automated clinical chemistry analyser (Roche Diagnostics
Corporation; Indianapolis, IN, USA) and commercially available reagents (Roche Diagnostics
Corporation; Indianapolis, IN, USA). Coefficients for the analyses of Mb, IL-6 and IL-10 were 0.9%, 2.2% and 1.4% respectively.

FABP concentrations were determined using a commercially available (Hycult Biotechnology, Uden, The Netherlands) two-site enzyme immunoassay kit. A standard curve of H-FABP concentrations versus absorbance values was constructed using Workout Software Version 2.0 (Dazdaq Ltd; East Sussex, United Kingdom). H-FABP concentrations for samples were determined by extrapolation from this standard curve. Results for each ELISA were accepted if the correlation coefficient for the standard curve was greater than 0.99 and high and low controls within established ranges. The coefficient of variation for duplicate samples was 11.7%.

5.2.9. Statistical analysis
Mean effects of the recovery treatments on muscle damage and inflammatory markers were estimated using the mixed model (Proc Mixed) in the Statistical Analysis System (Version 8.2 SAS Institute, Cary, North Carolina, USA). Given that players were on the court for different lengths of time, the mean cumulative game time was used as a covariate. Effects were expressed as factor changes by analysing log-transformed values. Precision of estimates were indicated with 90% factor confidence limits. Magnitude-based inferences of the effect of the recovery treatments were made by standardizing changes using between-subject pre-tournament standard deviations. Qualitative magnitudes of standardized effects were assessed using the following scale: trivial < 0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large >2.0.

5.3. Results
5.3.1. Daily pre- to post-game changes
Pre- to post-game increases were clear and very large for FABP after CWI (3.81 × factor mean 1.19, factor mean × factor SD), COMP (3.93 × 1.27) and CON (4.04 × 1.12) treatments. Increases in Mb were also clear and very large after CWI (3.50 × 1.37), COMP (3.36 × 1.29)
1.31) and CON (4.09 × 1.12). CK increases were clear but small after CWI (1.30 × 1.03), COMP (1.25 × 1.25) and CON (1.42 × 1.10) (Figure 5.1). There was no clear benefit from any recovery treatment, as the differences between treatments for all muscle damage markers at post-game measures were small or unclear.

There were clear moderate post-game increases in IL-6 for CWI (2.75 × 1.33), COMP (3.43 × 1.38) and CON (3.47 × 1.41). IL-10 increases were clear and moderate for CWI (1.75 × 1.52), clear and large after COMP (2.46 × 1.48) and CON (2.32 × 1.26) (Figure 5.2). There was no clear benefit from any recovery treatment, as the differences between treatments for IL-6 and IL-10 at post-game measures were small or unclear.
Figure 5.1. Concentrations of muscle-damage markers and cytokines during a three-game basketball tournament. Values are log-transformed mean ± SD. Moderate to very large increases were observed in the immediate post-game measure for FABP, Mb and cytokines. Compared to COMP and CON, CWI can have a moderate beneficial impact on reducing biomarker concentration the morning following a game. CK does not return to baseline prior to the next game, and these concentrations appear to plateau over the 3rd day.
5.3.2. Changes 6 h post game and recovery

Compared to post-game measures, at 6 post recovery intervention (Post 6h) serum concentrations for FABP had clear moderate to large decreases after CWI (0.47 ×⁄÷ 1.12, factor mean ×⁄÷ factor SD), COMP (0.51 ×⁄÷ 1.16) and CON (0.43 ×⁄÷ 1.34) respectively compared to post game measures. Mb had clear large to very large decreases after CWI (0.56 ×⁄÷ 1.11), COMP (0.53 ×⁄÷ 1.23) and CON (0.47 ×⁄÷ 1.17) treatments. CK continued to have clear small increases after CWI (1.18 ×⁄÷ 1.04), COMP (1.25 ×⁄÷ 1.21) and CON (1.26 ×⁄÷ 1.06).

Interleukin-6 had clear moderate decreases after CWI (0.51 ×⁄÷ 1.35), clear small decreases after COMP (0.57 ×⁄÷ 1.28), and clear moderate decreases after CON (0.46 ×⁄÷ 1.53). Similarly, IL-10 had clear moderate decreases after CWI (0.55 ×⁄÷ 1.64) and CON (0.62 ×⁄÷ 1.20), and clear large decreases after COMP (0.47 ×⁄÷ 1.23). There was no clear benefit of any recovery intervention being more useful in reducing cytokine concentrations at Post 6h, as the differences between treatments were small and unclear (Figure 5.2). Similarly, there was no clear impact on cytokine concentrations with only small and unclear differences between treatments (Figure 5.2).

5.3.3. Pre to post tournament changes

The cumulative effect of three days of competition play and the impact of recovery interventions on serum biomarkers are shown in Table 5.1. CWI recovery had the greatest impact on muscle damage marker concentration, with lower post-tournament elevations in FABP and Mb, but not CK, which had a moderate increase (Figure 5.1). For comparisons between recovery treatments, the decrease in damage marker concentrations were small to moderate for CWI when compared to CON. COMP appears to have minimal benefit as the comparisons to CON were generally unclear after the competition period (Figure 5.1).

Changes to cytokine concentrations were unclear after three days of competition. Additionally, there was no clear impact from any recovery intervention, with no difference between treatments for both IL-6 and IL-10 (Figure 5.2).
Figure 5.2. Concentrations of cytokines IL-6 and IL-10 during a three-game basketball tournament. Values are log-transformed means; error bars are SD. Post-game IL-6 had small decreases after CWI over the tournament compared to COMP and CON treatments.
Table 5.1. The effect of different recovery treatments on the pre to post-tournament changes in muscle damage marker and inflammatory cytokine concentrations (factor mean ×/÷ factor SD), with the associated effect size and qualitative outcome shown in italics. The magnitude of difference between treatments was assessed by using the criteria of: trivial < 0.2, small 0.2 – 0.6, moderate 0.6-1.2, large 1.2 – 2.0 and very large >2.0. CWI: cold-water immersion, COMP: compression garments, CON: stretching and CHO ingestion. ↑= increased concentration; ↓= decreased concentration.

<table>
<thead>
<tr>
<th>Changes</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>(factor mean ×/÷ factor SD)</td>
<td>(factor mean; ×/÷90% factor CL)</td>
</tr>
<tr>
<td><strong>Qualitative outcome</strong></td>
<td><strong>Qualitative outcome</strong></td>
</tr>
<tr>
<td>CWI</td>
<td>COMP</td>
</tr>
<tr>
<td><strong>Fatty-acid binding protein</strong></td>
<td><strong>Effect size; ±CL</strong></td>
</tr>
<tr>
<td>0.98 ×/÷ 1.15</td>
<td>1.16 ×/÷ 1.17</td>
</tr>
<tr>
<td>-0.03; ±0.24, Unclear</td>
<td>0.25; ±0.26, Small↑</td>
</tr>
<tr>
<td><strong>Creatine kinase</strong></td>
<td><strong>Effect size; ±CL</strong></td>
</tr>
<tr>
<td>1.90 ×/÷ 1.20</td>
<td>1.97 ×/÷ 1.30</td>
</tr>
<tr>
<td>0.83; ±0.23, Moderate↑</td>
<td>0.88; ±0.35, Moderate↑</td>
</tr>
<tr>
<td><strong>Myoglobin</strong></td>
<td><strong>Effect size; ±CL</strong></td>
</tr>
<tr>
<td>0.97 ×/÷ 1.13</td>
<td>1.17 ×/÷ 1.15</td>
</tr>
<tr>
<td>-0.10; ±0.38, Unclear</td>
<td>0.48; ±0.42, Small↑</td>
</tr>
<tr>
<td><strong>Interleukin-6</strong></td>
<td><strong>Effect size; ±CL</strong></td>
</tr>
<tr>
<td>1.02 ×/÷ 1.30</td>
<td>1.23 ×/÷ 1.60</td>
</tr>
<tr>
<td>0.02; ±0.24, Unclear</td>
<td>0.19; ±0.42, Unclear</td>
</tr>
<tr>
<td><strong>Interleukin-10</strong></td>
<td><strong>Effect size; ±CL</strong></td>
</tr>
<tr>
<td>0.87 ×/÷ 1.32</td>
<td>0.91 ×/÷ 2.49</td>
</tr>
<tr>
<td>-0.24; ±0.46, Unclear</td>
<td>-0.15; ±1.54, Unclear</td>
</tr>
</tbody>
</table>
Table 5.2. Pre-post tournament responses to muscle soreness (Visual Analogue Scale 1 – 10) and thigh girth measures (mm). Values are shown as raw means ± SD, with the associated effect size and qualitative outcome shown in italics. Outcomes were assessed by using the criteria of: trivial < 0.2, small 0.2 – 0.6, moderate 0.6–1.2, large 1.2 – 2.0 and very large >2.0. CWI: cold-water immersion, COMP: compression garments, CON: stretching and CHO ingestion. ↑= increase; ↓= decrease.

<table>
<thead>
<tr>
<th>Changes (raw means±SD)</th>
<th>Effects (mean; ±90% confidence limits)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect size; ±CL,</strong> Qualitative outcome</td>
<td><strong>Effect size; ±CL,</strong> Qualitative outcome</td>
</tr>
<tr>
<td>Changes over Tournament</td>
<td>COMP/CON</td>
</tr>
<tr>
<td>Muscle soreness (1-10)</td>
<td></td>
</tr>
<tr>
<td>CWI</td>
<td>COMP</td>
</tr>
<tr>
<td>1.3±0.7</td>
<td>1.9±0.8</td>
</tr>
<tr>
<td>2.60; ±1.32</td>
<td>3.89; ±1.55</td>
</tr>
<tr>
<td><strong>Very Large↑</strong></td>
<td><strong>Very Large↑</strong></td>
</tr>
<tr>
<td>Thigh Girth (mm)</td>
<td></td>
</tr>
<tr>
<td>-0.07±0.66</td>
<td>0.54±0.21</td>
</tr>
<tr>
<td>-0.01; ±0.13</td>
<td>0.11; ±0.04</td>
</tr>
<tr>
<td><strong>Trivial↑</strong></td>
<td><strong>Trivial↑</strong></td>
</tr>
</tbody>
</table>
5.3.4. Muscle soreness
Pre- to post-tournament leg muscle soreness (1-10 scale) increased substantially in all groups (Figure 5.3a). Players rated leg soreness after the first game at ‘uncomfortable’ (3 units), that increased to ‘sore’ (5 units) after the third game (Figure 5.3a). The immediate mean post-game muscle soreness rating was ‘somewhat sore’ (4.2 ± 1.4 units), which decreased to ‘normal’ (2.0 ± 0.7 units) after the CWI protocol. The perception of soreness rebounded back to ‘uncomfortable’ (3.1 ± 1.2 units) on the next morning. CWI was substantially better in minimizing soreness with large and very large decreases compared to COMP and CON. There were also large increases in soreness post-game, with no treatment having a clear benefit. On the morning following treatment, soreness decreased for all groups, with CWI and COMP having unclear small and trivial benefits respectively, compared to CON.

5.3.5. Thigh girth
The pre- to post-game and the morning after recovery intervention changes in mid thigh girth are shown in Table 5.2. Neither CWI nor COMP were more beneficial than CON, with trivial changes in thigh girth between treatments after a game, or the tournament (Figure 5.3b).
Figure 5.3. Muscle soreness (3a) and thigh girth (3b) during a three-game basketball tournament. Values are mean ± SD. Pre-values are measures taken on the morning prior to each game; Post-values are the measures taken immediately after each game. Soreness increased for all treatments over the tournament period. CWI can have a very large benefit in reducing muscle soreness compared to COMP and CON on the morning of the 4th day. Thigh girth increased slightly over the tournament period for COMP and CON, with a trivial decrease after CWI.
Figure 5.4. Schematic representation of the time line of events during the tournament period.
5.4. Discussion

The plasma concentration of several muscle damage markers and inflammatory cytokines increase substantially (up to ~4-fold) during tournament-style basketball competition, before returning to baseline concentration within 24 h. The application of immediate CWI or COMP has little benefit in decreasing biomarker concentrations measured 6 h after a game. However, using immediate CWI has a small to moderate benefit in enhancing biomarker clearance compared with COMP and traditional CHO/stretching routines between games during the competition period. After three days of competition CWI also had a moderate impact on decreasing biomarker concentration compared to COMP and CHO strategies. It appears that CWI recovery is a useful intervention in a multi-day basketball tournament setting.

The magnitudes of increase (~1.5 fold) in CK concentrations are substantially less than in previous studies of the effects of eccentric-based exercise, probably due to the extreme nature of previous protocols. However, these changes are consistent with the effects of concentric exercise.200 CK concentration may decrease slightly 10 h after concentric exercise, without returning to baseline within 24 h.211 This pattern of response may indicate that both eccentric and concentric exercise is responsible for mild membrane damage or increased permeability after a game. The time course of changes in FABP and Mb kinetics post-game were parallel to each other, with substantial reductions 6 h after play. The acute elevation and rapid clearance of FABP and Mb compared to the sustained elevation of CK indicates these biomarkers are more appropriate for quantifying alterations in muscle cell membrane permeability between games in tournament style competition.

It is reasonable to assume some degree of mechanical damage occurring due to the nature of basketball play. Previous reports from distance running suggested that increased serum concentration of CK and Mb may be a result of free radical induced membrane permeability, and not mechanical muscle damage.212 Increased free radical production during exercise may augment membrane permeability, allowing protein efflux into the circulation for detection.
post-exercise. Although we did not measure free radical concentrations, a limited free radical and metabolic response, causing a modest decrease in membrane integrity may explain our observations of relatively modest elevations in these biomarkers. Restoration of membrane integrity or biomarker normalization is not influenced by differing recovery treatments, particularly within the first 6 h. However, within 24 h and after the tournament we observed lower FABP and Mb, and a decrease in the rate of CK elevation for CWI in comparison with other treatments. Although a previous study indicated that a single bout of CWI has no benefit, our findings indicate (indirectly) that repeated daily CWI has a positive effect on restoring or maintaining membrane integrity during tournament style competition. One possible explanation may be the compounding effect of repeated daily exposure enhancing fluid gradients and fluid shifts due to the increased hydrostatic pressure uncounted during immersion.\textsuperscript{11, 136}

Both IL-6 and IL-10 concentrations increased sharply after each game, but it is unclear whether these elevations are related solely to an inflammatory response. The IL-6 kinetics observed immediately after basketball games are consistent with previous reports\textsuperscript{213-214} coinciding with the greatest neutrophil activity after exercise. However, as the post-exercise increases in IL-6 are dose dependent,\textsuperscript{214} the ~3-4 fold post-game increase observed following a basketball game is much lower than previously reported, and is presumably influenced by other factors. IL-6 has a regulatory role in CHO availability, and the serum concentration of IL-6 can be attenuated by CHO ingestion during running-based exercise.\textsuperscript{208} We restricted athletes from ingesting fluids containing CHO during play, but held intake constant between games. The acute post-game increase may be due to up-regulated signalling pathways associated with increased CHO availability during play. Additionally, IL-6 may increase due to a progressive increase in core temperature,\textsuperscript{215} which presumably occurred during the games. The observed changes in IL-10 concentration provide indirect evidence of an activated inflammatory cascade directly after a game. However, it is unclear if IL-10 is produced in reaction to a localised production of IL-6 within a generalised inflammatory response,\textsuperscript{216} or to
an elevated IL-6 concentration associated with other metabolic factors, which may, or may not be related to muscle damage.

The benefits associated with CWI observed in the current study may be related to redistribution of oedema from enhanced fluid gradients, shunting of increased peripheral blood to the central blood volume related to hydrostatic pressure,\textsuperscript{11, 136} or pain inhibition. The combination of cold water and hydrostatic pressure may have enhanced lymph flow, decreasing oedema. Lymph evacuation is influenced significantly when cold water is applied with or without pressure.\textsuperscript{217} In contrast, the level of compression created by commercial garments was not sufficient to elicit a substantial impact. The biphasic response in muscle soreness coincides with the acute changes in biomarkers following games. Lowering of muscle temperature may be one explanation for the greater decrease in pain perception immediately, and the morning after CWI application. Lowering tissue temperature by 10-15°C inhibits the pain-spasm cycle by reducing nerve conduction velocity, muscle spindle activity, muscle spasticity and the stretch-reflex response.\textsuperscript{218} The compounding affect of repeated daily exposure may account for the substantial benefit observed with CWI compared to other treatments.

There was large variation in the individual post-game responses between players. The immediate explanation of this may be the between-subject differences in workloads. However our analysis accounted for cumulative game time as a covariate, essentially normalizing game time across all players. Therefore, the variation in results indicates that certain players may be more or less susceptible to alterations in myocyte membrane permeability, or have differing biomarker clearance rates. Regardless of the mechanism, the findings suggest a need for individualized recovery programs. Further research is required to develop a practical method for identifying and managing players requiring more extensive, or intensive recovery after training and competitive games.
5.5. Conclusions

Tournament-style basketball play elicits modest elevations of muscle damage markers in the circulation suggesting disruption of myocyte membrane permeability in well-trained players. The magnitude of increase in muscle damage markers and inflammatory cytokines post-game ranged from small for creatine kinase, to very large for fatty acid binding protein and myoglobin. Small to moderate decreases in biomarker concentration were evident after the tournament using cold-water immersion compared to compression, and carbohydrate/stretching routines. The application of compression garments appears to have little advantage in enhancing clearance over consecutive days, but a study with a larger sample size is needed to resolve this issue. Repeated competition initiates acute localized membrane permeability and restoration, with an associated inflammatory cytokine response. However it is unclear if this is a true inflammatory response associated with mechanical damage, or other metabolic mechanisms. Cold-water immersion provides an acute analgesic effect and appears most effective in enhancing recovery after repeated application. Players should undertake this form of recovery as part of the regular post-game management. Further research is required to determine the effectiveness of other water-based treatments such as contrast hot and cold-water immersion, and the physiological mechanisms underpinning improved recovery in the team-sport setting.
Chapter 6.
Seasonal progression and variability of repeat effort line-drill performance in junior basketball players.

6.1. Introduction

Tests of athletic performance are widely used by many team sports to assess the progression of various fitness characteristics in players within a season, and over a career. In basketball, the line-drill test has been a popular and widely employed performance test of speed endurance, speed agility and court coverage specific to basketball. The line-drill test is typically completed in ~28 s for males, and ~31 s for females depending on position, playing level and current level of fitness. Although the line-drill test has previously been considered an acceptable field measure of anaerobic capacity for basketball players, there is only one study that has assessed the changes in line-drill performance within a season. In that report, large improvements in performance (~2 s) were made in 12 junior male players in the preparation phase, with performance maintained over the remainder of the season. Very small performance decrements were also observed following a month of higher training volume within the season. No reference was made to the magnitude of change within a season or the variation between positions.

Coaches generally expect that fitness should be maintained during a season, although realistically fitness may increase or decrease in some players over a season. Aerobic capacity in basketball generally increases during the pre-season phase, and falls back to initial levels or remains unchanged during the competition phase. This pattern has also been shown in other team sports. One study of male players reported increased aerobic capacity after a detraining period toward the end of a competition phase compared to the in-season phase. The anaerobic component of basketball has been reported critical to success. Anaerobic capacity has been previously reported to increase over a pre-season phase and then remain unchanged during the competition phase. Anaerobic testing has
generally been performed using variations of the Wingate Anaerobic Test, repeat jump tests or the Magaria-Kalaman stair climb test. Although these tests are valid for assessing anaerobic power, the specificity to the movement patterns of basketball is questionable. The specificity and use of the line-drill test during the annual training plan should be much more transferable and meaningful for basketball coaches.

Specific basketball practice is purportedly the best method of improving the fitness characteristics of basketball. The physiological and movements demands consist of repeat-efforts ranging from low to maximal intensity. Other factors that can influence the demands of basketball include game tempo, quality of opposition, style of play and recovery interventions used by the coach. The combined impact of these factors over a competitive season may elicit a variable pattern of responses (positive, neutral, or negative) depending on the adaptability of individual athletes. An unexplored aspect of these seasonal changes in fitness is whether they are linear in nature, or more likely, show a variable (non-linear) pattern.

Basketball players are roughly characterised by position, however there is no literature detailing the magnitudes of differences in fitness characteristics between basketball positions, or in the expected magnitude of fitness improvements within training and competition periods. The development of normative data for the rate of progression within- and between-seasons for individual positions and genders would provide coaches with valuable information for player selection, development and improvement. The aim of this study was to quantify the magnitude of within-subject changes in basketball line-drill performance in elite junior basketball players within a season, and over an extended developmental period. A secondary aim was to quantify the magnitude of differences in line-drill performance between genders, and between different playing positions.
6.2. Methods
Participants were 93 junior males aged 16.8 ± 1.1 y (mean ± standard deviation (SD)); height 1.98 ± 0.10 m; body mass 91.4 ± 13.0 kg; Σ7 skin folds 61.3 ± 21.7 mm, and 95 junior females aged 16.5 ± 1.0 y; height 1.81 ± 0.7 m; body mass 71.5 ± 9.6 kg; Σ7 skin folds 91.3 ± 25.5 mm. All participants were State and national level players participating in National Intensive Training Centre Programs (NITCP; n=59 males, 56 females) of Basketball Australia (BA), or were full-time basketball scholarship holders at the Australian Institute of Sport (AIS; n=34 males, 39 females). Typical training of the participants comprised 3-4 full team practices (90-120 mins each), 1-2 individual shooting and skill sessions (30-45 mins each), and 3 strength training sessions for AIS scholarship athletes (60 mins); for a total training load of ~10-12 h per week.

6.3.1. Experimental design
This study involved a retrospective observational analysis of sequential performance testing. Successive yearly groups of Australian Junior Camp attendees, or AIS scholarship holders, undertook 516 basketball line-drill tests over an eight year period (1998 – 2005). Players generally completed the line-drill test on 2.8 ± 2.4 occasions over 1.0 ± 1.2 y. All participants performed the tests at national Junior Camps or during routine testing sessions as part of the AIS scholarship programme. Participants (or parent/legal guardian) provided written informed consent for testing, data collection, and publication of results as part of their scholarship agreement with the AIS and BA NITCP. All testing was approved by the Ethics Committee of the AIS. All line-drill tests were completed on an international regulation sized court. Players were tested in afternoon sessions (1600 -1800 h) having rested ~22 h since any previous practice. A standardised 10-min warm-up involving low-high intensity running, static and dynamic stretches was provided. Players were advised of the importance of a quality pre-test meal (lunch, consumed 3 h before testing) and fluid replacement, although these were not controlled at the individual level.
6.3.2. Performance test

The line-drill test has been described previously and requires players to run continuously at maximal effort over a total distance of 140 metres. Players ran in pairs during the test to create a competitive element, with each player hand timed by an individual assessor. All players were instructed to place their preferred turning foot on the line at each turning point; the test was terminated and repeated after adequate rest if a player was short of the line for any turn. Tests were classified by the phase of season in which they were performed (1. Early Pre-Season, 2. Late Pre-Season, 3. Early Season, 4. Late Season).

6.3.3. Statistical analysis

Data modelling involved precision of estimation of changes in line-drill performance, and characterisation of the practical importance of the changes and differences rather than strict hypothesis testing. All performance measures were log-transformed and back-transformed to obtain changes in means and variations as percents (coefficients of variation). Descriptive statistics are reported as mean ± standard deviation.

A mixed-modelling procedure was used to estimate means (fixed effects) and within- and between-subject variations (random effects, modelled as variances). The fixed effects were gender (female, male), position (guard, forward, and centre), time within a season (0-1 yr), and scholarship time (0-3 yr). The random effects were a between-subject variance, a within-subject within-season variance representing variation in line-drill performance from test to test, and the within-subject variance between seasons. The within-season and overall scholarship time trend were estimated with a quadratic analysis. We anticipated longer term changes (seasons to years) would not necessarily be linear and therefore a quadratic expression was deemed more appropriate for several of the positions as it was the simplest way of addressing the curvature in a trend. The between-subject effects of starting age and starting year were modelled against the mean age (17 y) and mean year (2004) of program entry. The precision of estimates was indicated with ±90% confidence limits. Magnitudes of standardized mean differences were quantified using the following descriptors: <0.2 trivial,
0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.9 large and >2.0 very large.185 The smallest worthwhile change in performance from test to test was established as a ‘small’ effect size (0.2 x between-subject SD) according to methods outlined previously.185 All analyses were performed with the Statistical Analysis System (Version 8.2, SAS Institute, Cary, NC or Statistica 6.0 (Statsoft, Tulsa, Oklahoma, USA).

6.4. Results

6.4.1. Line-drill testing
Mean line-drill run times were 28.0 ± 1.3 s for males and 30.4 ± 1.3 s for females. The distribution of tests across gender and position, and the associated mean performance times are shown in Table 6.1.

<table>
<thead>
<tr>
<th>Number of tests</th>
<th>Performance time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>74 ± 1.5</td>
</tr>
<tr>
<td>Forwards</td>
<td>91 ± 1.2</td>
</tr>
<tr>
<td>Guards</td>
<td>77 ± 1.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>44 ± 1.7</td>
</tr>
<tr>
<td>Forwards</td>
<td>95 ± 1.4</td>
</tr>
<tr>
<td>Guards</td>
<td>135 ± 1.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
</tr>
</tbody>
</table>

6.4.2. Effect of position at program entry
At program entry time, female centres were substantially slower than Guards 7.2% (±3.8%) and forwards 4.3% (±3.7%). Forwards 3.0% (±2.9%) were also slower than guards. Male centres were substantially slower than Guards 6.0% (±2.9%) and forwards 5.0% (±2.7%), while forwards were slower than guards by 1.0% (±3.1%).
6.4.3. Within-subject changes in line-drill performance within a season

The smallest worthwhile performance change in the line-drill test for females was estimated as 0.8%. There was a variable quadratic pattern of changes within a season by position for female players (range -3.5[faster] – 1.6[slower]%). Female centres showed a very large improvement of 3.5% at the late pre-season and early competition phase, but did not maintain this improvement through to the end of the season (Figure 6.1). Female forwards did not have any worthwhile progression in line-drill performance during any phase of the season. Female guards exhibited a very large decrease of ~2% at the late pre-season phase, and although they improved their performance through the competition phase, there was no overall worthwhile improvement by the end of the season (Figure 6.1).

Male players also showed variable quadratic patterns of change in performance by position within a season (range -1.1[faster] – 2.4[slower]%). The smallest worthwhile performance change in line-drill performance for males was established as 1.0%. Male guards and centres did not have any worthwhile progression in performance during any phase of the season. Male forwards showed a very large decrease of ~2% in performance at the late pre-season and early season phase (Figure 6.1).

6.4.4. Longitudinal performance improvements over scholarship period

Overall improvements in line-drill performance for male and female individual positions during their scholarship period are expressed as mean changes (Figure 6.2). There was a non-linear improvement of ~1 second for both males 1.4% (±1.3%) and females 2.9% (±1.4%) over this period. Male guards improved by 1.0 second 3.6% (± 2.1%), centres 0.7 s 2.5% (±2.1%), and forwards by 0.3 s 1.1% (±2.0%). Female forwards had the greatest improvement of 1.3 s 4.2% (±1.7%), followed by centres 0.7 s 2.2% (±2.3%), and guards 0.6 s 2.0% (±1.7%).
Figure 6.1. Percentage changes in line-drill performance for males and females within a basketball season. The shaded area represents the smallest worthwhile change (calculated as 0.2 x between-subject SD; males =1% (0.28 s), females 0.85% (0.26 s)) for the line-drill test, the vertical line (─) represents the expected typical variation for an individuals test within a season (males =1.95% (0.6 s), females =1.89% (0.6 s)) and the solid vertical bars are the 90% confidence limits.
Figure 6.2. Percentage change in line-drill performance for males and females for the length of time in the basketball scholarship program. The shaded area represents the smallest worthwhile change (calculated as 0.2 x between-subject SD; males =1% (0.28 s), females 0.85% (0.26 s)) for the line-drill test, the vertical line (Γ) represents the expected typical variation for an individuals test within a season (males =1.95% (0.6 s), females =1.89% (0.6 s)) and the solid vertical bars are the 90% confidence limits.
Table 6.2. Percentile rankings for performance changes within a season for the basketball line-drill. A lower rank (e.g. 10th percentile) indicates the player’s line-drill result (seconds) is in the bottom 10% of expected performance times for that period of the season. Data is based on all positions.

<table>
<thead>
<tr>
<th>Males</th>
<th>95th Percentile</th>
<th>90th Percentile</th>
<th>75th Percentile</th>
<th>50th Percentile</th>
<th>25th Percentile</th>
<th>10th Percentile</th>
<th>5th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Pre</td>
<td>26.2</td>
<td>26.3</td>
<td>26.7</td>
<td>27.9</td>
<td>28.4</td>
<td>29.8</td>
<td>31.4</td>
</tr>
<tr>
<td>Late Pre</td>
<td>26.1</td>
<td>26.3</td>
<td>27.0</td>
<td>28.0</td>
<td>28.9</td>
<td>29.7</td>
<td>30.4</td>
</tr>
<tr>
<td>Early season</td>
<td>25.6</td>
<td>26.1</td>
<td>26.3</td>
<td>27.3</td>
<td>28.0</td>
<td>28.7</td>
<td>29.2</td>
</tr>
<tr>
<td>Late season</td>
<td>26.3</td>
<td>26.5</td>
<td>26.9</td>
<td>27.7</td>
<td>28.4</td>
<td>30.2</td>
<td>30.7</td>
</tr>
</tbody>
</table>

Females

| Early Pre    | 28.6            | 28.6            | 29.5            | 30.4            | 30.9            | 32.1            | 32.6          |
| Late Pre     | 28.4            | 28.8            | 29.1            | 29.7            | 30.5            | 31.4            | 31.8          |
| Early season | 28.3            | 28.6            | 29.5            | 29.9            | 30.6            | 31.5            | 32.0          |
| Late season  | 28.4            | 28.7            | 29.2            | 30.3            | 31.0            | 32.1            | 32.8          |

6.4.5. Between-subject effects

The expected rate of improvement per year for males was 0.2% (±0.5%), and females 0.6% (±0.4%) per year. For each year older in age that athletes started in the program, males were 0.4% (±0.9%) faster, while females were 0.9% (±0.7%) faster. There was also a substantial effect of age between positions. The line-drill performance of male 19 year old centres (26.8 ± 1.1 s), forwards (25.4 ± 1.0 s) and guards (25.2 ± 1.1 s), was substantially faster than 15 year male centres (29.2 ± 0.8 s), forwards (27.7 ± 0.8 s) and guards (27.4 ± 0.8 s). Similarly, female 19 year old centres (31.5 ± 1.7 s), forwards (30.2 ± 1.4 s) and guards (29.2 ± 1.4 s) were substantially faster in the line-drill test than 15 year female centres (33.0 ± 1.2s), forwards (31.6 ± 0.7 s) and guards (30.6 ± 0.8 s). For each additional year of program intake, there were small improvements for male 0.2% (±0.5%), and moderate decrements for female 0.6% (±0.4%) line-drill performance.
6.4.6. Reference values

Percentile rankings for line-drill performance are shown in Table 6.3. Independent of position, to remain above the 50th percentile at any phase of the season, elite junior male players require a performance time of 26.1 – 27.0 s. Similarly, junior female players will require performance times of 28.6 – 29.5 s to be in the top half of their cohort.

6.5. Discussion

The main finding of this study is that the repeat-effort (line-drill) performance in junior basketball players changes substantially within a playing season, and improves with seasonal conditioning. These variable patterns of line-drill performance within a season are heavily influenced by gender and playing position. In practical terms, an anticipated improvement in performance for males will be 0.1-1.3 s, and females of 0.3-1.5 s over a competition year. However, there is substantial variation between positions and gender about these improvements such that some individual players may be slower. Team sport fitness comprises dynamic physiological attributes that change with the differing training and competition loads experienced over a season, not only in basketball but other team sports.19 166 Athlete preparation prior to performance testing is important in ensuring reliability of results; poor preparation prior to testing in this study may be an explanation for negative performances. We have shown that the capability of elite junior basketball players to maintain line-drill ability, which has been reported as predominantly underpinned by anaerobic capacity32 110 can change substantially over a season.

Interpreting changes in team sport performance throughout a season requires consideration of the positive impact of training against the negative influence of training related fatigue. Previous research has indicated that anaerobic fitness per se when assessed by step tests or cycle ergometry does not change substantially over a basketball season.4 45 110 222 The failure to identify substantial changes may reflect limitations in the sensitivity of the fitness tests employed.166 However, if an athlete’s capacity to meet the high-intensity demands of competition remains constant over a season, then seasonal performance changes
in line-drill ability may relate to fatigue induced by training and competition, rather than a true lack of specific fitness.

**6.5.1. Positional differences**

Basketball players are broadly categorized as centres, forwards and guards as a function of height and playing responsibilities within the team structure. The positional differences in line-drill performance were as expected, with male guards similar to forwards, but substantially faster than centres. Female guards were substantially faster than forwards, who in turn were substantially faster than centres. Repeat-effort ability and court coverage are demands imposed on all positions. However the stature and body mass of players in forward and centre positions, together with their specific offensive and defensive roles limits performance relative to guards. Independent of gender, guards enter elite programs with greater court coverage ability than other positions, but the rate of development for females within a single season, is less than centres and forwards. Similarly, male guards show a trivial improvement within a season compared to centres but not forwards. Speed agility and speed endurance are characteristics central to the guard position. These players may enter programs with these characteristics already developed. These attributes may have been developed over many years of specific conditioning from game demands in junior basketball, or transferred from abilities developed in other sports. A higher initial level of fitness may be one explanation why a smaller rate of progression is observed over a season for both male and female guards.

**6.5.2. Performance changes over scholarship period**

A key question for coaches and players is whether there has been substantial improvement in ability over their scholarship period. Female forwards and centres show a substantial performance progression early in the program, while guards failed to show worthwhile progression until the end of the 1st scholarship year. This non-uniform rate of progression represents the typical (mean) progression of fitness across various playing positions. A greater
rate of adaptation for centres and forwards indicates that taller players are more responsive to the new training and competition environment than their shorter team mates. Although guards and forwards continued to make very large improvements throughout the scholarship period, we observed a plateau in the line-drill performance of female centres by the end of their 2nd scholarship year; with very large decreases (2%, 0.7 second) in ability over the remainder of their time in the program. Coaches should consider position-specific conditioning programs for new players, with a basic level of specific training for centres and forwards, and advanced programs for guards who posses higher levels of ability.

Male guards showed a continual linear improvement in line-drill performance until the end of their scholarship period; forwards and centres also improved their line-drill ability, with maximal gains by the midpoint of the 2nd year. The rate of progression was similar for these two positions, but the absolute change in performance was greater for centres, although not to the magnitude of guards by the end of the scholarship. The difference in performance progression between positions did not become substantial against the typical within-season variation between positions until the middle of the last scholarship year. Collectively these findings indicate non-uniformity in line-drill progression, although the magnitude of variation in performance across positions is similar. Coaches and practitioners can generally expect all positions to improve at the same rate for the early stages of a development period, with performance of taller players showing a plateau in the latter stages.

The greater rate and magnitude of improvement for females compared with males may be related to the training volume and intensity experienced in junior programs. Training volume and intensity in junior programs is considerably less than the requirements of elite level programs and the short-term response to the increased training stimulus may amplify improvements in line-drill performance. The analyses indicate that court coverage ability in taller male players and female centres begins to plateau or decrease after ~2 yrs. This stabilisation or decrement in performance may be related to maturational effects as taller players continue to increase in total body mass, and combined with the limitations of their
stature, presumably restrict the ability to move with the same level of speed and agility as previous years. Evidence on adolescent awkwardness is scarce, however it appears that for some running and explosive strength tests there is a transient decrease in performance in the year prior to, during and after the 1st year after the peak growth spurt.223

6.5.3. Within-season changes

Females show the greatest magnitude of change within a season, in particular those players of taller stature. This is characterised by a rapid adaptation to early season training, followed by a reversal in fitness as the cumulative training and competition load presumably have a negative impact. This curvilinear performance profile would not be favourable to ensure peak condition at the critical finals period of the season. Female forwards show little response to the training and competition demands within a season, however over the longer scholarship period of ~2 yrs, they show very large substantial improvement. The continual improvement over the longer period may reflect maintenance of fitness between consecutive competitive seasons. In contrast to centres, female guards exhibited a negative pattern of change in line-drill performance; this biphasic deterioration in line-drill performance during the late pre-season phase is followed by worthwhile improvement towards the end of the season. This pattern of change may reflect the variations in training and/or the different competition demands between positions that occur within a season. Greater specificity of repeat-effort demands between training and competition, and increased recovery time between games and practice, may have favourable adaptations for the guards in the latter part of the season.

The explanation for female centres showing greater improvement within a season and over a scholarship may relate to a lower initial level of fitness at recruitment than forwards and guards. It is clear that centres enter development programs with a below average court coverage ability possibly reflecting a lower anaerobic capacity, or limited specific physical conditioning in junior programs. It is unlikely that there is a learning effect for the line-drill test in the study period as these players use the test repeatedly during their junior development programs. Taller players may come from programs where they rely more on their stature for a
competitive advantage over physical or physiological capacities. Entering an environment of increased athleticism, increased repeat-effort type training and increased competition against faster more agile players may translate into improved performance. We speculate that late season decrements in test performance may be indicative of physical and physiological fatigue associated with the competition period. Moreover, detraining during the off season impairs performance at the beginning of the next season.224-226 These findings reinforce the need for careful management of conditioning within and between seasons.

Male players across the playing positions also show variable patterns of improvement within a season. Forwards show a very large (2.4%, 0.7 s) impairment of line-drill performance during the early season phase. Figure 6.1 shows clearly that the change is substantially greater than the smallest worthwhile change; however the variation around the test is greater than the expected variation for an individual. Coaches should interpret the results based on the magnitude of the change, being mindful of the variation at any given point of the season. Centres have a similar pattern to forwards with their performance, but with a non substantial, smaller magnitude of change within the season. Guards have a trivial peak in their performance at the end of the late pre-season phase, but generally have non substantial changes in performance. Conservative approaches to on-court training demands, limiting game time where appropriate for high load players, and aggressive recovery strategies may all assist in maintaining fitness and limiting mid season performance decrements.

The explanation for the differing expressions of performance change within seasons between male and female positions, in that females and males may increase or decrease in performance is unclear. Athletes may have been at differing stages of development, in which growth and sex hormones can play a significant role in muscle strength and power development.227 Despite the short-term fluctuations in performance, coaches and players can be reassured that moderate to very large improvements in performance are gained over several years of development. This improvement only becomes substantial after the first year
in the program for both genders. These findings reinforce the notion that variable patterns of (substantial) change in performance can occur within a busy season of training and competition.

The reference values generated in this study for Line-drill test scores during a season are the first of their kind published for a basketball-specific test. The percentile rankings indicate how well a player has performed compared with all other players at a certain phase of the season. For example, a player who achieves a line-drill time of 26.2 s in the early pre-season phase will be faster than 95% of the other players tested, or is in the top 5% for line-drill ability at that phase. This information should be useful for coaches, conditioners and players for assessing the current level of repeat-effort fitness during each phase of the season. These rankings may also assist coaches in discriminating between players for selection, and provide feedback for players rehabilitating from injury.

6.6. Conclusion
Changes in court coverage ability between positions in junior basketball within a season are variable in nature, with small to large magnitudes, in both positive and negative directions. The magnitudes of many of these changes are substantial in performance terms. Improvements in line-drill performance over the scholarship period are moderate to very large in magnitude for both males and females. The expected rate of progression in line-drill performance is ~1 s per year, with typical variation of 1.1 – 3.6% for males and 2.0 – 4.2% for females. The reference values produced for expected changes within a season for positions across both genders in a widely used training and performance drill provide a quantitative framework for the interpretation of changes in repeat-effort fitness for a given player within- and between-seasons, and between playing positions. Practitioners can now be more confident in assessing whether observed changes in court coverage ability are worthwhile. Further research into the interaction of training loads and individual positional demands during competition is required to identify the causes of the variable changes in fitness levels occurring within a basketball season.
Chapter 7.
The physical and physiological demands of basketball training and competition.

7.1. Introduction
The development of wearable, miniaturised smart sensor devices has provided new avenues of research in the sport sciences, including investigating the demands of team sports. Although the movement characteristics of basketball competition have been documented in a small number of time-motion studies, little is known regarding the physical demand, with respect to whole body movement, or the associated physiological response to offensive and defensive drills, and game play. Consequently, how these responses contribute to, and impact on the overall training and/or competition exercise is not well understood.

Time-motion analysis shows that players may cover ~3.5 – 5.7 kilometres during a basketball game, comprising many high speed movements in forward and lateral directions combined with decelerations from frequent sprint efforts. Explosive vertical jumps may be executed up to 50 times per game. Heart rate and blood lactate concentration have been the main focus of investigations into physiological demands. Competition for elite males may elicit maximal heart rate values up to 190 beat·min⁻¹. More recently, mean heart rates of 171 beat·min⁻¹ or 91% of the maximal heart rate have been recorded during play. Measures of blood lactate concentration indicate that anaerobic metabolism makes a substantial contribution to the supply of energy for muscular contraction. Mean values for male basketball players have been recorded at 8.5 ± 3.1 mmol·L⁻¹, and 5.7 ± 2.1 mmol·L⁻¹ during international level female games. However, blood lactate is only a surrogate indicator of anaerobic metabolism, as concentrations may be ~⅓ of the muscle concentration, and are influenced by the exercise intensity immediately prior to sample collection. Heart rate may be a limited indicator of aerobic metabolism during basketball due to rapid movements of upper body segments, cardiovascular drift, or an altered autonomic tone. Despite
preliminary efforts to describe some of the physiological aspects of basketball play, the aerobic (VO₂) energy demands of competition are unknown.

Recently, the development of personal heart rate telemetry systems incorporating predictive software can provide real-time estimates of the VO₂ during training and competition. The Suunto™ personal heart rate monitoring system includes software for estimation of VO₂ based on methods developed by Firstbeat Technologies Ltd (Jyväskylä, Finland). These systems offer great flexibility for team sport practitioners as multiple players can be monitored, and their heart rate and VO₂ responses viewed in real time. This methodology offers coaches and support staff the opportunity to modify the intensity (or duration) of a training session if objectives are not being met. Competition intensity can also be quantified, allowing training drills of similar intensity to be designed. The Suunto™ system has shown to be reliable, with a typical error of 0.64 ml·kg⁻¹·min⁻¹ (~1.5%) and a coefficient of variation of (6%). This degree of reliability (accuracy) is sufficient in characterising moderate or larger changes or differences in aerobic capacity (>6%) rather than smaller subtle changes.

Tri-axial accelerometers are now available which are relatively unobtrusive for use during team sport training and competition. Accelerometers have been used extensively in the general population setting as a measure of physical activity. The physical demands of team sports have been evaluated using Global Positioning System (GPS) technology. GPS may be appropriate in outdoor settings which allow satellite reception, but is unusable for indoor sports such as basketball. To our knowledge, only one study has been conducted in basketball and other high intensity team sports that quantified the physical demands by using accelerometer technology. Accelerometers were used in boy’s basketball with moderate correlations between accelerometer output and heart rate. The authors concluded that accelerometers were sensitive enough to quantify the physical demands and the intensity level during a typical basketball session. However, the accelerometer used in that study was a uni-axial version, and possibly underestimated the true physical demands as only one plane of
movement was measured. To gain further insight into the demands of basketball using accelerometer technology, player movement should be measured in all three planes (triaxial accelerometry). Many offensive and defensive basketball movements are combinations of forward, backward and/or lateral movements. These rapid movements presumably combine to elicit a substantial physical demand, and associated physiological responses. Given that previous time-motion observations predominantly focused on running, the aim of this study was to quantify differences in whole body dynamics (physical demand), heart rate and predicted VO₂ responses (physiological demand) between selected offensive and defensive training drills, reduced court area competition (5on5 scrimmage), and live game play.

7.2. Subjects
Eleven elite junior male players (age 19.1 ± 2.1 y, height 1.91 ± 0.09 m, mass 87.9 ± 15.1 kg, maximal heart rate 201 ± 4 beat·min⁻¹, estimated VO₂ max 68.6 ± 1.3 ml·kg⁻¹·min⁻¹, Σ7 skinfold 68.9 ± 32.1 mm; mean ± SD) volunteered to participate in the investigation. The study was approved by the Ethics Committee of the Australian Institute of Sport (Approval Number 20060803), and all players were verbally informed of the study requirements, and provided written informed consent prior to commencement.

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

7.4. Methods
To validate the whole body movement characteristics captured by the accelerometer, we conducted a controlled validation trial of a defensive movement drill ("close outs"). We used this trial given its movement patterns formed the basis of many of the drills performed during the training sessions. We employed a construct validity approach to determine if there were substantial differences in outputs derived from the accelerometer data across several trials of the same movement patterns. This type of validity relates to basketball attributes (constructs) which cannot easily be measured (e.g. non-quantifiable actions such as multi-segmental movement). We hypothesized that if there were trivial differences between the validity trials, then we could be confident that (dis)similarities in the physical demands between offensive and defensive drills would be represented accordingly. The trial required players to perform the same close-out movement pattern (within a 5 x 5 m grid) at maximal intensity in both left and right directions, in random order. In total, players completed 12 trials, 6 with and 6 without an opponent. All heart rate and accelerometer data during the validation trials, training and competition periods was normalised for actual playing time; that is, only the data related to actual live play or live drill time was processed using LoganPlus v4 (Catapult Innovations, Melbourne, Australia). All variables for each player were divided by the drill duration providing normalized outcomes independent of time.
The whole body movements of training and competition were expressed as the accumulated load. This estimate of physical demand combines the instantaneous rate of change in acceleration in three planes of body movement; up/down (z), side/side (y) and forward/backward (x) according to the formula:

\[
Load = \sqrt{\left((Ac_1^n - Ac_1^{n-1})^2 + (Ac_2^n - Ac_2^{n-1})^2 + (Ac_3^n - Ac_3^{n-1})^2\right)}
\]

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

Peak heart rate (HR\text{\text{\textsubscript{peak}}}) for each player was determined by completing the YoYo intermittent recovery test\textsuperscript{235} using the Suunto™ system. Heart rate measures during the training sessions were then expressed as a percentage of this HR\text{\textsubscript{peak}}, and the mean heart rate during the training or game period.

All players had their peak VO\textsubscript{2} determined during the YoYo intermittent recovery test while using the Suunto™ system. Predictions of VO\textsubscript{2} were determined within the Suunto™ software. The analysis required the specification of the participant’s basic personal information of age, mass, height, gender and level of activity. The software then provided a predicted maximal oxygen capacity. Individual HR\text{\textsubscript{peak}} as determined from the YoYo test was added to this information for each player’s profile to improve the predicted accuracy of the
VO₂ measures. Although the predicted value may be ~2.7 ml·kg⁻¹·min⁻¹ below the true value when compared to a calibrated metabolic cart\textsuperscript{160}, the addition of HR\text{peak} improves the accuracy by 7%. Based on our previous research\textsuperscript{231} which estimated the typical error of measurement as 1.8%, and the smallest worthwhile difference in VO₂ as ~2.3 ml·kg⁻¹·min⁻¹ (calculated as 0.2 x between-subject SD), we were confident that any practical/clinically meaningful (significant) differences in the VO₂ between training drills, or play conditions would be identified.

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

7.5. Statistical analysis

Differences in the means for defensive and offensive drills, 5on5 scrimmage and live play conditions were compared using log-transformed data as per methods outlined previously.\textsuperscript{236} Precision of estimates were indicated with 90% confidence limits, which defines the range representing the uncertainty in the true value of the (unknown) population mean. Magnitude-based inferences for the differences between conditions were made by standardizing differences using the between-subject standard deviation. A substantial difference was classified as ≥75% likelihood of the effect statistic being greater than or equal to the ES (±0.2) (small). Unclear effects were designated when the ±90%CL of the ES crossed the boundaries of −0.2 and +0.2. Qualitative magnitudes of standardized effects were assessed using the following descriptive scale: trivial < 0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large >2.0.\textsuperscript{237}
7.6. Results

Descriptive statistics (mean ± SD) for the raw values of accelerometer and physiological variables measured are shown in Table 7.1. The mean (± SD) duration of offensive and defensive drills were 5:28 ± 1:51 and 4:29 ± 1:41 min:s.

When normalised for time there were only trivial differences between the validation trial, defence and offence drills for the majority of variables. There was no clear difference in physical demand between offensive and defensive drills (Figure 7.1), or mean and peak heart rate (Table 7.2). There was a moderate but substantially greater VO₂ requirement (6% difference; ~2.9 ml·kg⁻¹·min⁻¹) for defensive compared with offensive drills (Figure 7.2).

Figure 7.1. The accumulated physical load for basketball training drills and competition as determined by tri-axial accelerometry after being normalised for time in each condition. Values are arbitrary units (a.u). Error bars show the SD. Moderate difference between 5on5 and live play; ES, 1.17 (±0.65). # indicates substantial difference to all drills.
Table 7.1. Raw values (mean ± SD) for accumulated load (Acc load), peak and mean heart rate (HR), oxygen use (VO\textsubscript{2}) and the rate of perceived exertion (RPE) during various forms of basketball training and competition.

<table>
<thead>
<tr>
<th>Drill</th>
<th>Acc load (arbitrary units/min)</th>
<th>Peak HR (beat·min\textsuperscript{-1})</th>
<th>Mean HR (beat·min\textsuperscript{-1})</th>
<th>VO\textsubscript{2} (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</th>
<th>VO\textsubscript{2} (%)</th>
<th>Mean RPE (1-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation trial</td>
<td>14 ± 3</td>
<td>166 ± 14</td>
<td>147 ± 15</td>
<td>42.9 ± 5.5</td>
<td>62 ± 1</td>
<td>7</td>
</tr>
<tr>
<td>Defence</td>
<td>13 ± 5</td>
<td>170 ± 7</td>
<td>152 ± 7</td>
<td>45.1 ± 3.6</td>
<td>66 ± 5</td>
<td>7</td>
</tr>
<tr>
<td>Offence</td>
<td>15 ± 9</td>
<td>165 ± 6</td>
<td>147 ± 5</td>
<td>42.3 ± 3.0</td>
<td>63 ± 6</td>
<td>7</td>
</tr>
<tr>
<td>5on5</td>
<td>21 ± 11</td>
<td>171 ± 12</td>
<td>147 ± 10</td>
<td>40.2 ± 7.1</td>
<td>59 ± 10</td>
<td>9</td>
</tr>
<tr>
<td>Game</td>
<td>30 ± 6</td>
<td>173 ± 6</td>
<td>162 ± 7</td>
<td>51.2 ± 3.4</td>
<td>70 ± 16</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: %VO\textsubscript{2} refers to a % of the peak value achieved during the YoYo test; a.u refers to arbitrary units.
Figure 7.2. Oxygen demand values during training and competition expressed as a percentage of predicted VO$_2$ (a), and the peak values during each drill or live play (b). Error bars show the SD. Large difference were evident between live play and 5on5; ES, 1.97 (±0.62). * are greater than the smallest clinical difference (~3 ml·kg$^{-1}$·min$^{-1}$) for predicted VO$_2$. 
Mean duration for 5on5 drills, and the isolated periods of live play were 8:37 ± 4:56 and 9:30 ± 3:26 min:s respectively. The physical demand of live play is substantially more demanding than 5on5 or offensive and defensive drills (Figure 7.1). VO\(_2\) (31% difference; ~5.4 ml·kg\(^{-1}\)·min\(^{-1}\); Figure 7.2), mean and peak heart rates are substantially more intense during live play than a 5on5 scrimmage (Table 7.2).
Table 7.2. Differences in the estimates of physical and physiological demands between defensive and offensive drills, and 5on5 and live competition.

<table>
<thead>
<tr>
<th></th>
<th>Difference between defence and offence</th>
<th>Difference between live play and 5on5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% difference (90%CL)</td>
<td>Effect size (±90%CL)</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Accumulated load</td>
<td>10 (-25 to 59)</td>
<td>0.26 (±1.08)</td>
</tr>
<tr>
<td></td>
<td>Unclear</td>
<td></td>
</tr>
<tr>
<td>Peak heart rate</td>
<td>-1 (-4 to 3)</td>
<td>-0.20 (±0.77)</td>
</tr>
<tr>
<td></td>
<td>Unclear</td>
<td></td>
</tr>
<tr>
<td>Mean heart rate</td>
<td>-2 (-6 to 2)</td>
<td>-0.51 (±0.88)</td>
</tr>
<tr>
<td></td>
<td>Unclear</td>
<td></td>
</tr>
<tr>
<td>Mean estimated VO$_2$</td>
<td>-6 (-13 to 3)</td>
<td>-0.69 (±1.02)</td>
</tr>
<tr>
<td></td>
<td>Unclear</td>
<td></td>
</tr>
</tbody>
</table>

Note: Comparisons between conditions are shown as %, (90% confidence limit (CL)). The magnitude of difference between conditions was assessed with the following criteria: trivial < 0.2, small 0.2 – 0.6, moderate 0.6-1.2, large 1.2 – 2.0 and very large >2.0. A substantial difference was classified as a ≥75% likelihood of the effect statistic being greater than or equal to the ES (±0.2) (small). Unclear effects were designated when the ±90%CL of the ES crossed the boundaries of 0.2 and +0.2. Negative values represent lower demand. Data has been adjusted for minutes completed within each form of training or live play, except for VO$_2$ which was collected in relative values.
7.7. Discussion
Within the team sport environment, estimations of physical and physiological demand are often limited by the cost and effectiveness of the available technology. Cost effective wearable sensor technology permits more systematic monitoring of the physical demands and physiological responses during training and competition. Time-motion analysis and heart rate were traditional criterion methods to assess and understand physical demands, and intensity in team sports. We have shown that the combination of heart rate, accelerometry, and heart rate-predicted VO$_2$ information can be used to differentiate the physical and physiological demands during certain aspects of basketball training and competition.

During basketball practice, players will experience similar physical demands and physiological responses to the execution of offensive or defensive drills. Coaches are often concerned with the amount of training that occurs during the training week, and the implication this volume may have on subsequent performance. Recognising that the main conditioning component may be the competition itself, basketball coaches can now have a deeper understanding that weekly training sessions can focus on the tactical offensive and defensive components of team play and rely on the competition, which may comprise several games in as many days, to maintain player condition. Astute coaches will periodise the training schedule to accommodate the demands of weekly competition. Recognising that multiple games will increase physical and physiological demands and reduce subsequent performance, and recovery of players, initial training sessions of the following week may need to be of lower intensity. Coaches armed with information regarding the intensity and demands of drills can structure lighter sessions early in the week, and develop demanding 5on5 type scrimmage drills later in the week as playing-related soreness decreases.
Competitive live games have substantially greater physical and physiological demands compared to a 5on5 scrimmage play. The higher demands of a live game are likely a consequence of the players competing over the whole court, rather than half-court in the 5on5 scrimmage. However the contribution from the individual planar axes needs to be quantified to determine where the majority of movement is accumulated during game exercise. Intuitively, the forward/backward contribution from the additional running up and down the court during transition creates an increased physical load, and physiological response. Similarly, there may also be increased movement intensity during offensive evasive, and defensive reactive movements, which may also contribute to an increase in physical demand.

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

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

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

7.8. Practical applications

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

7.9. Conclusions

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

Chapter 8.
Discussion

The purpose of this thesis was to quantify the physical and physiological demands of basketball practice and competition, determine the utility of emerging technology in performing such quantification, and assess the effectiveness of recovery strategies in minimising the magnitude of competition-related fatigue. The results show that the demands of training and competition can be determined using predicted oxygen uptake values as determined by personal heart rate telemetry. This new technology shows to be reliable, with appropriate sensitivity to discriminate between practice drills. Combining this heart rate based information with outcomes from accelerometers shows that the physical demands are similar between offensive and defensive practice drills, but simulated game play does not meet the demands of game play. During tournament play, or successive games during the regular season, small - moderate amounts of acute fatigue and muscle damage occur, but the use of cold-water immersion recovery (5 x 2 minutes @ 11 °C) can have small - moderate benefits in alleviating these performance limiting factors. Coaches should be aware that substantial fatigue may occur in the ability to repeat high-intensity efforts. A single game can elicit acute mild muscular disruption, which is maintained over several days of repeated play. Although cold-water immersion appears to have no benefit in the clearance of IL-6, IL-10, FABP and Mb during the immediate hours after a game, using immediate cold-water immersion has a small - moderate benefit in enhancing the clearance of these biomarkers compared with compression and traditional routines between games, and after three consecutive games. Although not strictly measured here, on the basis of these findings a recommendation to basketball coaches and practitioners would be to structure practice sessions to focus on lower intensity tactical elements earlier in the training week following games, and
progress to higher intensity game specific practice later in the week. Practitioners involved with long-term development programs for junior athletes, can expect improvement of ~1 s in the repeat effort ability per year. This outcome is highly variable dependant on position and gender, with some players getting slower, and reflects that within a season there can be substantial changes to physical performance possibly linked to training and competition loads. However, over longer periods (i.e. 3 years) the general level of improvement is 1.4% and 2.4% for junior male and female basketball players.

The first study of this thesis evaluated the viability of athlete heart rate monitoring systems that have the capacity to deliver real-time physiological information. This assertion by the manufacturers is intriguing as it provides the possibility of quantifying the physiological responses of team-sport athletes, in particular basketball players, during practice sessions and live competition. This ability would allow coaches and scientists to identify and quantify similarities, and differences in the demands of training and competition. The information should lead to prescription of more specific and effective training; however the validity and reliability of these telemetry systems had not been clearly defined. Although the Suunto™ heart rate monitoring system showed substantial underestimation of 2.7 ml·kg\(^{-1}\)·min\(^{-1}\) in oxygen uptake (and a standard error of ~6%) when compared to a calibrated metabolic cart, the inclusion of a known physiological variable such as maximal heart rate increased the agreement (less bias) with the criterion measure. It was evident that the system would be suitable for the assessment of moderate to larger changes in maximal aerobic power, rather than small discrete changes associated with highly-trained athletes. Therefore, the system is not suitable for use in the field or laboratory as a surrogate for a metabolic cart. In contrast, the system showed a high degree of test-retest reliability with typical error values of 0.6 ml·kg\(^{-1}\)·min\(^{-1}\) (1.5%), making it suitable for the repeated assessment of individuals in the field. However, the determination of energy expenditure in high intensity, sport-specific tasks is less feasible. The underestimate of ~6 kJ,
along with a high CV of ~13% using the Suunto™ system highlights a limitation in the algorithms to accurately predict energy expenditure. The outcome from this research is that practitioners and scientists should have confidence in this technology to provide useful physiological information during team sport training and competition. The oxygen uptake of basketball, and team sport athletes, can be estimated unobtrusively and with serial monitoring the quantification of practice and competition demands can be determined.

Structured basketball competition involves repeated games over several days. During international tournaments, teams often play up to three games in as many days in pool rounds. In the regular home and away season, teams are required to play repeated games with only one day, or often no daily breaks which is compounded by the demands of short and long haul travel. Consequently, it is intuitive that some fatigue occurs after basketball competition, and the severity of this fatigue would be related to the volume and intensity of play. However the magnitude of this fatigue was not understood, nor the impact that this fatigue would have on physical performance. Supplementary to fatigue-related performance decrements was the premise that emerging recovery strategies routinely used by teams may have useful effects in maintaining performance, or minimising fatigue related decrements.

The results of Chapter 4 show that accumulated fatigue is evident within tournament style competition. Substantial small - very large cumulative fatigue from three consecutive days of competition was evident in several performance measures, and elevations in subjective ratings of general fatigue. There were small impairments in repeat effort assessments of court coverage of 1.4 ± 1.7 %; a moderate decrement in 20m acceleration of 0.5 ± 1.4%; and a large - very large decrement in specific agility of 2.0 ± 1.9%. Lower back range of movement and hamstring flexibility as determined by the sit & reach test decreased by 5.4 ± 4.0 cm, and general fatigue had a very large increase of 2.2 ± 1.5 arbitrary units (scale 1-10). Fatigue of losing teams may be a reason for improved 3-point shooting, and ultimate success of their opponents. Therefore
these results confirm that accumulated fatigue of physical fitness characteristics could impact game outcome, and limiting these decrements may aid in competitiveness.

Repeated cold-water immersion provides small - moderate benefits in maintaining repeat effort performance and acceleration by limiting the magnitude of performance decrements when compared with compression garments and traditional carbohydrate and stretching practices. Most notable is the ~1 s improvement in line-drill performance after cold-water immersion. As repeat effort ability is an important component to basketball play, the competitive advantage of ~1 s from using cold-water immersion is an important factor for coaches and trainers to consider. If a player has a greater capacity to cover the court and maintain intensity and performance during accumulated repeat efforts, and high intensity play then this could form a competitive advantage. A team’s best players often shoulder most of the playing time to maximise a team’s likelihood of success. The modelling in this thesis shows that a starting player required to play up to 8:26 min:s of additional game time will also benefit the most from cold-water immersion recovery. These players can expect small - moderate improvements in performance and very large decreases in muscle soreness as playing time increases. Although the use of cold-water immersion appears more favourable, this strategy may not always be practical. The alternative use of full leg compression garments appears to have minimal benefit on the majority of performance parameters within basketball, and provide no (additional) benefit with increasing game participation time.

The finding of substantial decrements in physical performance from repeated basketball games raises the question of an underlying mechanism. As basketball play contains a high volume of eccentric muscular load, micro-trauma to muscle tissue could be one explanation for limitations in physical capacity after a single, or series of games. The results from Chapter 5 indicate that tournament-style basketball play elicits modest elevations of muscle damage markers in the circulation, suggesting some disruption of the myocyte membrane or transient increased membrane permeability. The magnitude of increase in muscle damage markers and
inflammatory cytokines post-game ranged from small for creatine kinase, to very large for fatty acid binding protein and myoglobin. Few studies have been completed in team sport profiling the relationship of competition and muscle damage.244-246 The findings from chapter 5 are novel in the team sport area, in particular detailing the time course changes of muscle damage markers after a single, or repeated games.

Small to moderate decreases in biomarker concentration were evident after the tournament using cold-water immersion compared to full leg compression garments, and carbohydrate/stretching routines. The application of compression garments appears to have little advantage in enhancing biomarker clearance over consecutive days. This finding is a contradiction of previous research following a rugby match that reported enhanced clearance of creatine kinase.133 As the current results indicate, creatine kinase is an unreliable marker of muscle damage in basketball, or tournament style competition due to the slow rate of removal, and the appearance after both concentric and eccentric exercise.211 This last point is particularly relevant as basketball and other team sports, which require substantial volumes of both concentric and eccentric forms of muscular activity. Therefore the interpretation of creatine kinase concentration changes cannot be easily achieved, and provides little insight into exercise related muscular disruption in team sport.

Repeated competition initiates an acute period of localised membrane permeability and restoration. The elevated IL6 and IL10 concentrations reflect an associated inflammatory cytokine response.216 However it is unclear if elevations in these biomarkers represent a true inflammatory response associated with mechanical damage,216 a metabolic response due to increased core temperature,215 or increased carbohydrate availability.208 In any case, cold-water immersion provided an acute analgesic effect and appears most effective in enhancing recovery after repeated application. Coaches and trainers should ensure their players undertake this form of recovery as part of the regular post-game management.
Collectively, the research undertaken here suggests that physical fatigue is a limiting factor to the physical aspects of basketball performance, and intuitively a player with a greater degree of fatigue will execute specific skills at a lower level. Additionally the nature of basketball play creates a degree of disruption to the exercising musculature creating a cascade of events that may exacerbate performance. However the use of structured and repeated cold-water immersion will ameliorate these effects with greater benefit than traditional carbohydrate/stretching routines, or commercially-available compression garments. The research also confirms the practical application of water-based recovery techniques in team sport.

Repeat-effort ability is a physical characteristic of team sports and basketball that is paramount to success, particularly for players such as guards and forwards involved in fast transitions into the offensive and defensive court. Within basketball programs this court coverage ability is generally tested using the line-drill test. National junior coaches were concerned that this physical attribute was decreasing in junior players on an annual basis. Explanation for this decline was thought to relate to large in-season training and competition loads, or that development programs were limited in their effectiveness in developing this attribute. This shortcoming would potentially lead to elite teams, at both junior and senior levels entering international competitions with limitations in their physical capacities.

The investigation of Chapter 6 involved a retrospective analysis of line-drill performance records of junior basketball players attending national selection camps over a 5-year period. First, the findings confirmed that performance results may be highly variable within a season for both males and females, and generally there will be a decrease in repeat effort performance over a season. However, the long term development in this area is positive and substantial, particularly for both male and female guards, and forwards, who are more heavily involved in the transitional aspects of play. Players competing in the centre position typically improve over
In the initial two years of a development program, but this improvement plateaus for both males and females.

The within-season observations imply that coaches and trainers should utilise conservative approaches to on-court training demands during the season, and limit game time for high load players where appropriate. Additionally, the management of player demands, through periodisation of training and competition loads should be addressed to ensure players maintain peak performance through the season.

The critical outcomes from this research are that coaches of basketball programs looking to expedite player development should consider alternative conditioning programs for players in specific positions, particularly female centres. A basic level of specific training for centres and forwards will produce an exponential improvement in repeat-effort ability. Coaches should also recognise that advanced programs are required for guards who already possess higher levels of ability. These advanced programs should be orientated to maintenance rather than development, as the implementation of a high-intensity program may create overload issues for these players if they accumulate higher training and game loads. Coaches and trainers should critically compare performance development with the knowledge that the expected rate of progression in repeat effort line-drill performance is ~1 s per year, with typical between-athlete variation of 1.1 – 3.6% for males and 2.0 – 4.2% for females.

The final study of this thesis investigated and compared the practice and competition environments of basketball. By incorporating the specific use of the technology validated in study 1 in combination with triaxial accelerometry, the study quantified the physiological and physical demands of both domains. It was expected that the defensive and offensive drills used within a practice session would have differing physiological and physical demands, in that the reactive agility and velocity required to respond to an opponent during defensive drills would
increase the physical and physiological demands. Moreover, that reduced court 5on5 style play would have similar responses compared to live competition. The research determined that there was no clear difference in physical demand between offensive and defensive drills. In terms of a physiological response, there was also no substantial difference in the mean and peak heart rate during these drills. However, there was a moderate but substantially greater oxygen demand (6% difference; ~2.9 ml·kg⁻¹·min⁻¹) for defensive compared with offensive drills. The results from study 1 concluded that the smallest worthwhile difference in VO₂ that could be determined from the Suunto™ system was 2.3 ml·kg⁻¹·min⁻¹, this confirms that the Suunto™ system is sensitive enough to discriminate worthwhile changes in VO₂ requirements during drills. Given that defensive pressure appears to decrease as fatigue increases,¹⁴,³⁷ it should be a consideration that specific basketball training should involve conditioning drills that have a higher physiological demand during the defensive aspects. The higher oxygen demand will ultimately relate to cumulative fatigue for the defensive players. Therefore having well developed strength endurance, and a well developed VO₂ to meet repeat-effort demands will limit fatigue, and scoring advantage for opponents.

Competitive live games have substantially greater physical and physiological demands than a 5on5 drill. This drill is a practical way of increasing skill and tactical training, without excessive increases in physical and/or physiological demand. Other research⁷ has concluded that the mean VO₂ demands for males during second-tier college level game play when assessed by a portable analyser (VO2000; Medical Graphics) is ~36.9 ± 2.6 ml·kg⁻¹·min⁻¹. This value is considerably lower than the 51.2 ± 2.4 ml·kg⁻¹·min⁻¹ reported in this thesis. The authors of the previous research used a portable metabolic system, of which the validity and reliability was not documented, which may be one explanation for the difference, as the error associated with portable systems may be as high as ~20%, as discussed previously. The predicted maximal values from both studies were considerably different (57.5 ± 8.2 ml·kg⁻¹·min⁻¹ compared to 68.6 ± 1.3 ml·kg⁻¹·min⁻¹ in this thesis), which may be another explanation for the differences.
Additionally, the design of Narazaki et al.\textsuperscript{7} employed 4 x 5-minute play periods, whereas the mean playing period of study 5 was \textasciitilde10 minutes, therefore the extended playing periods may have contributed to a higher VO\textsubscript{2} response. Taken together, the mean relative intensity of a live play period requires and oxygen demand that is 65 – 70\% of maximal. However the highly intermittent nature of basketball play demands periods of maximal intensity, with a large proportion of game time spent at, or above anaerobic threshold levels. Consequently, having well developed cardiovascular fitness cannot be underestimated by basketball coaches and conditioning staff. A well developed aerobic energy system will promote the recovery from repetitive short-duration explosive activities, and continual running of various intensity experienced during play.

This thesis has explored the physiological and physical demands of basketball practice and competition, and the effectiveness of practical recovery strategies to maintain performance during competition. Given the requirements of international junior and senior competition is based on tournament style consisting of repeated games over several days, much of the research in this thesis was designed to simulate these competitions. Therefore a major aim of this research was to provide practical information to national coaches and support staff that would aid in securing success during international competition. The thesis has determined the degree of fatigue associated with tournament style competition, and concluded that jumping, sprinting and repeat effort ability will be most affected. There is evidence of muscle disruption and an associated inflammatory response following repeated games, with fatty acid binding protein and myoglobin having a higher level of sensitivity to game demands than creatine kinase. The concentrations achieved for these biomarkers were lower than previous studies of muscle damage following running-based exercise. These differences were most likely attributable to the volume of eccentric load experienced during distance running, and the familiarity of basketball play for experienced players not creating large amounts of cellular damage. However, as this
was the first study of muscle damage in basketball, further research is needed to determine if these are typical responses. Previous studies have highlighted the limitations of using creatine kinase as an indicator of eccentric-based muscle damage. This thesis confirms these reports particularly in team sport. Given that elevations in creatine kinase concentration can occur from concentric-based exercise, and those concentrations remain elevated, this protein provides little information on the transient nature of muscle soreness/damage associated with tournament style play. Creatine kinase also appears of little value as a marker of muscle damage in other elite team sports where training and competition may be separated by 48 h.

There is a growing body of literature surrounding the use of water-based recovery strategies during and after team sport exercise. Supplementary to this evidence is the growing commercial agenda of companies supplying compression garments claiming to have substantial benefits. Although there are no strict guidelines recommended for recovery, the outcomes of this thesis indicate that teams competing in tournament style competition, or playing a series of invitational international games, should favour the use of repeated (5 x 2 min @ 11 °C) cold-water immersion post game in combination with carbohydrate/stretching over wearing compression garments alone.

Sport scientists working in basketball programs are now in a position to advise development coaches of the long term improvements associated with court coverage ability. Coaches who are suitably informed will be able to structure training to meet the needs of individual players, and have guidelines surrounding the expected rate of progression for their athletes. Coaches are also now able to contextualise the degree of performance decrement that typically occurs in repeat-effort performance during a season of basketball, and develop long term plans to enhance development accordingly.

Within a single practice session, coaches can now have a deeper understanding of the demands surrounding defensive, offensive, and 5on5 drills in comparison to live play.
Regardless of player participation in defensive or offensive drills, the physical and physiological responses are likely to be similar. The physical demand of these drills is substantially less than reduced court 5on5 style play and live competition. Coaches can use these drills during the initial days after competition when fatigue and muscle damage/soreness are likely to be at their greatest. The coach is able to maintain technical training, and progress to higher intensity tactical and structural practice later in the week. Trainers should consider that 5on5 style play will elicit a similar cardiovascular response as live play, however the demands of 5on5 are substantially lower than live play, and although the drill may provide some conditioning effects, it is unlikely to be an effective substitute for live play. Therefore, other conditioning modalities such as high-intensity interval running, boxing and high-intensity cycling may need to be introduced to increase or maintain cardiovascular fitness while reducing load.

8.1. Final comments and future directions

There are striking similarities in the physical demands of defensive and offensive drills, but the intensity of these practice drills or activities are substantially lower than live play. The demands of competition will result in decrements of repeat effort court-coverage ability within a season, and tournament style play will negatively impact on performance and produce transient signs of muscle damage. Both of these detrimental aspects can be mediated by cold-water immersion recovery, but not compression garments. Future investigations could use the emerging accelerometry technology to define the contribution of the predominant plane of movement to total demand in both training and competition. Additionally, modelling of the combined physical and skill related performance decrements during the tournament environment would be invaluable in the holistic understanding of how accumulated playing loads contribute to skill and team success.
Reference list


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