Muscular strength, fitness and anthropometry in elite junior basketball players

Submitted by
Eric J Drinkwater
B.P.E, M.P.E.

School of Human Movement, Recreation and Performance
Centre for Ageing, Rehabilitation, Exercise and Sport
Victoria University

Initial Submission: February, 2006
Revised Submission: August, 2006

A thesis submitted in fulfillment of the requirements for the degree
Doctor of Philosophy

Supervisor:
Professor Michael J. McKenna
School of Human Movement, Recreation and Performance
Centre for Ageing, Rehabilitation, Exercise and Sport
Victoria University
Melbourne, Victoria
Australia

Co-Supervisor:
Associate Professor David B. Pyne
Department of Physiology
Australian Institute of Sport
Canberra, ACT
Australia
This thesis is supported by the following publications:


This thesis is supported by the following conference presentations:

**Drinkwater EJ**, Lawton TW, Lindsell RP, Pyne DB, Hunt PH, McKenna MJ. Repetition failure is a key determinant of strength development in resistance training. 51st AGM of the American Collage of Sports Medicine, Indianapolis, Indiana, USA. 2-5 June 2004.

STUDENT DECLARATION

“I, Eric Drinkwater, declare that the PhD thesis entitled *Muscular strength, fitness and anthropometry in elite junior basketball players* is no more than 100,000 words in length, exclusive of tables, figures, appendices, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.”

_________________________________

Eric Drinkwater
# TABLE OF CONTENTS

STUDENT DECLARATION ........................................................................................................ III
TABLE OF CONTENTS ........................................................................................................ IV
LIST OF TABLES .................................................................................................................. IX
LIST OF FIGURES ................................................................................................................ X
ACKNOWLEDGEMENTS ....................................................................................................... XI
THESIS ABSTRACT ............................................................................................................. XIII

CHAPTER 1: THESIS INTRODUCTION .......................................................................... 1
CHAPTER 2: REVIEW OF LITERATURE ........................................................................... 5
  2.1 Introduction .................................................................................................................... 5
  2.2 Physical Testing Of Fitness And Anthropometry ..................................................... 7
    2.2.1 Importance of Body Size and Fitness for Basketball ....................................... 7
    2.2.2 Fitness Testing for Basketball ......................................................................... 10
    2.2.3 Normal Variations and Changes in Physical Tests ......................................... 14
    2.2.4 Changes in Physical Fitness Over a Calendar Year ....................................... 16
    2.2.5 Concern About Fitness By Coaches ............................................................... 20
    2.2.6 Resistance Training to Improve Fitness ........................................................... 22
  2.3 Fatigue And Failure In Resistance Training ......................................................... 36
    2.3.1 Overview of muscle contraction .................................................................... 36
    2.3.2 Neural Inhibition ............................................................................................. 39
    2.3.3 Metabolic Fatigue and Lactate ........................................................................ 41
    2.3.4 Other By-products and Sources of Ionic Imbalance ...................................... 44
    2.3.5 Muscular Failure .............................................................................................. 45
  2.4 Training Programs ...................................................................................................... 47
    2.4.1 Resistance Training Adaptations and Benefits to Team Sport Athletes .......... 50
      2.4.1.1 Neural Adaptations ..................................................................................... 50
      2.4.1.2 Fibre Adaptations ...................................................................................... 54
      2.4.1.3 Metabolic ..................................................................................................... 56
    2.4.2 Critique of Past Resistance Training Research for Sporting Applications .... 57
    2.4.3 Resistance Training To Improve Sport-Specific Power Output ....................... 60
    2.4.4 Summary of Benefits of Resistance Training to Athletes ............................... 63
  2.5 Summary ..................................................................................................................... 64
  2.6 Aims And Hypotheses ............................................................................................... 67

CHAPTER 3: MODELING AGE AND SECULAR DIFFERENCES IN FITNESS BETWEEN JUNIOR BASKETBALL PLAYERS .............................................. 71
  3.1 Introduction .................................................................................................................. 71
  3.2 Methods ....................................................................................................................... 72
    3.2.1 Subjects ............................................................................................................. 72
    3.2.2 Experimental Design ....................................................................................... 73
    3.2.3 Description of Tests ........................................................................................ 73
      3.2.3.1 Anthropometric Measurements .............................................................. 73
      3.2.3.2 Fitness Tests .............................................................................................. 74
    3.2.4 Fitness Test Reliability ...................................................................................... 74
    3.2.5 Statistical Analyses ......................................................................................... 75
  3.3 Results ......................................................................................................................... 76

STUDENT DECLARATION .............................................................................................. III
TABLE OF CONTENTS ........................................................................................................ IV
LIST OF TABLES .................................................................................................................. IX
LIST OF FIGURES ................................................................................................................ X
ACKNOWLEDGEMENTS ....................................................................................................... XI
THESIS ABSTRACT ............................................................................................................. XIII

CHAPTER 1: THESIS INTRODUCTION .......................................................................... 1
CHAPTER 2: REVIEW OF LITERATURE ........................................................................... 5
  2.1 Introduction .................................................................................................................... 5
  2.2 Physical Testing Of Fitness And Anthropometry ..................................................... 7
    2.2.1 Importance of Body Size and Fitness for Basketball ....................................... 7
    2.2.2 Fitness Testing for Basketball ......................................................................... 10
    2.2.3 Normal Variations and Changes in Physical Tests ......................................... 14
    2.2.4 Changes in Physical Fitness Over a Calendar Year ....................................... 16
    2.2.5 Concern About Fitness By Coaches ............................................................... 20
    2.2.6 Resistance Training to Improve Fitness ........................................................... 22
  2.3 Fatigue And Failure In Resistance Training ......................................................... 36
    2.3.1 Overview of muscle contraction .................................................................... 36
    2.3.2 Neural Inhibition ............................................................................................. 39
    2.3.3 Metabolic Fatigue and Lactate ........................................................................ 41
    2.3.4 Other By-products and Sources of Ionic Imbalance ...................................... 44
    2.3.5 Muscular Failure .............................................................................................. 45
  2.4 Training Programs ...................................................................................................... 47
    2.4.1 Resistance Training Adaptations and Benefits to Team Sport Athletes ........ 50
      2.4.1.1 Neural Adaptations ..................................................................................... 50
      2.4.1.2 Fibre Adaptations ...................................................................................... 54
      2.4.1.3 Metabolic ..................................................................................................... 56
    2.4.2 Critique of Past Resistance Training Research for Sporting Applications .... 57
    2.4.3 Resistance Training To Improve Sport-Specific Power Output ....................... 60
    2.4.4 Summary of Benefits of Resistance Training to Athletes ............................... 63
  2.5 Summary ..................................................................................................................... 64
  2.6 Aims And Hypotheses ............................................................................................... 67

CHAPTER 3: MODELING AGE AND SECULAR DIFFERENCES IN FITNESS BETWEEN JUNIOR BASKETBALL PLAYERS .............................................. 71
  3.1 Introduction .................................................................................................................. 71
  3.2 Methods ....................................................................................................................... 72
    3.2.1 Subjects ............................................................................................................. 72
    3.2.2 Experimental Design ....................................................................................... 73
    3.2.3 Description of Tests ........................................................................................ 73
      3.2.3.1 Anthropometric Measurements .............................................................. 73
      3.2.3.2 Fitness Tests .............................................................................................. 74
    3.2.4 Fitness Test Reliability ...................................................................................... 74
    3.2.5 Statistical Analyses ......................................................................................... 75
  3.3 Results ......................................................................................................................... 76
3.3.1 Fitness Test Reliability ................................................................. 76
3.3.2 Level (State versus National) ...................................................... 77
3.3.3 Gender ....................................................................................... 79
3.3.4 Age Differences at Recruitment (14-19 y) ................................ 79
  3.3.4.1 Anthropometry ................................................................. 79
  3.3.4.2 Fitness .................................................................................. 80
Figure 3.2 - State male vertical jump .................................................. 82
3.3.5 Secular Differences (1996-2003) ................................................. 82
  3.3.5.1 Anthropometry ................................................................. 82
  3.3.5.2 Fitness .................................................................................. 82
  3.3.5.3 Age ..................................................................................... 83
3.4 Discussion ..................................................................................... 85
  3.4.1 Age Differences at Recruitment ................................................. 85
  3.4.2 Secular Differences ................................................................. 86
  3.4.3 Program Level and Gender Differences ...................................... 87
  3.4.4 Implications of Test Variability .................................................. 89
3.5 Conclusions ................................................................................... 91
3.6 Conclusion ...................................................................................... 92

CHAPTER 4: CHARACTERIZING CHANGES IN FITNESS OF BASKETBALL PLAYERS WITHIN AND BETWEEN SEASONS ........................................ 92
4.1 Introduction .................................................................................... 92
4.2 Methods ......................................................................................... 94
  4.2.1 Subjects ....................................................................................... 94
  4.2.2 Experimental Design ................................................................. 94
  4.2.3 Description of Tests ................................................................. 95
    4.2.3.1 Anthropometric Measurements ........................................... 95
    4.2.3.2 Fitness Tests ................................................................. 96
  4.2.4 Fitness Test Reliability ............................................................... 97
  4.2.5 Statistical Analyses ................................................................. 97
4.3 Results ......................................................................................... 99
  4.3.1 Phase Changes ................................................................. 99
  4.3.2 Years in the Program ............................................................... 100
  4.3.3 Within-Athlete (Individual) Variation ...................................... 103
  4.3.4 Between-Athlete Variation ....................................................... 105
4.4 Discussion ................................................................................... 105
  4.4.1 Changes in Fitness from Phase to Phase within a Year ............... 106
  4.4.2 Longitudinal changes from year to year ................................... 107
  4.4.3 Individual Variation in Fitness .................................................. 110
4.5 Conclusion .................................................................................... 112

CHAPTER 5: VALIDATION OF A OPTICAL ENCODER DURING FREE WEIGHT RESISTANCE MOVEMENTS AND ANALYSIS OF BENCH PRESS STICKING POINT POWER DURING FATIGUE ........................................ 113
5.1 Introduction .................................................................................... 113
5.2 Methods ......................................................................................... 115
  5.2.1 Approach to the Problem ......................................................... 115
  5.2.2 Subjects ....................................................................................... 116
  5.2.3 Procedures ................................................................. 117
    5.2.3.1 Lifts Evaluated ................................................................. 117
    5.2.3.2 Optical Encoder ............................................................... 118
7.3.1 Pre-Training Testing ................................................................. 169
   7.3.1.1 Relationship between strength and power ....................... 169
   7.3.1.2 Assessing Magnitudes of Change .................................... 170
7.3.2 Training Analyses ................................................................. 170
   7.3.2.1 Training Compliance ....................................................... 170
   7.3.2.2 Number of Forced Repetitions ....................................... 171
7.3.3 Kinematic Analysis of Bench Press ........................................... 172
   7.3.3.1 Concentric time ............................................................ 172
   7.3.3.2 Total Work ................................................................. 172
   7.3.3.3 Concentric Mean Power ............................................... 174
7.3.4 Effects of Strength Training .................................................... 174
   7.3.4.1 Strength and Power Test ............................................... 174
   7.3.4.2 Anthropometric Changes ............................................. 174
7.4 Discussion ..................................................................................... 175
7.5 Practical Applications ............................................................... 177

CHAPTER 8: THESIS DISCUSSION AND CONCLUSION ...................... 179
8.1 Modeling fitness trends ............................................................... 179
   8.1.1 Differences between newly recruited players ....................... 179
   8.1.2 Changes within players over time ....................................... 180
8.2 Resistance Training ................................................................. 181
   8.2.1 Gymaware validity to measure bench press kinetics ............... 181
   8.2.2 Changes in kinetics with fatigue ....................................... 182
   8.2.3 Bench press training to repetition failure ........................... 183
   8.2.4 Bench press training involving forced repetitions ............... 184
   8.2.5 Conclusions ...................................................................... 186
8.3 Future Directions ........................................................................ 187
REFERENCES .................................................................................. 189

APPENDIX A – RAW DATA FOR STUDIES 1 & 2 .............................. 209
APPENDIX B – RAW DATA FOR STUDY 3 ....................................... 210
   B.1 Mean Power (reference: Figure 5.4) .................................. 210
   Subject1 .................................................................................. 210
   Subject2 .................................................................................. 210
   Subject3 .................................................................................. 210
   Subject4 .................................................................................. 210
   Subject5 .................................................................................. 210
   Subject6 .................................................................................. 210
   Subject7 .................................................................................. 210
   B.2 Peak power, first phase (reference: Figure 5.5) .................. 211
   B.3 Low power, second phase (reference: Figure 5.6) ............ 212
   B.4 Peak power – third phase (reference: Figure 5.7) ............ 213
   B.5 Criterion (Video) versus Practical (Gymaware) Power Output (reference: Table 5.1) .......................................................... 214
APPENDIX C – RAW DATA FOR STUDY 4 ....................................... 217
   C.1 Fitness Tests (reference: Figure 6.1 and 6.2) ....................... 217
APPENDIX D – RAW DATA FOR STUDY 5 ....................................... 218
   D.1 Fitness Tests (reference: Table 7.3 and Figure 7.1) ........... 218
LIST OF TABLES

Table 2.1 - Anthropometry and physical fitness test scores………………………………………13
Table 2.2 – Fitness changes in a periodised program………………………………………………18
Table 2.3 - The use of resistance training in improving performance in court sport related tests…………………………………………………………………………………25
Table 2.4 - The use of resistance training in improving performance in sporting event related tests…………………………………………………………………………………27
Table 2.5 - The use of resistance training in improving performance in laboratory-based tests……………………………………………………………………………………31
Table 3.1 - Differences between levels of players…………………………………………………78
Table 4.1 - Within-player variations in fitness……………………………………………………104
Table 5.1 - Validity of Gymaware™ optical encoder power calculation compared with video (criterion measure) power calculations……126
Table 6.1 - Number of sets trained in each session at each of the weekly training intensities expressed as a percent of 6RM…………………148
Table 7.1 - Summary of Age and Anthropometric Measures of Participants………..162
Table 7.2 - Summary of training group programs illustrating differences in training intensity as a percent of 6RM, starting time, and the number of repetitions performed in each set……………………………………167
Table 7.3 - Summary of pre-training strength and power testing comparing groups……………………………………………………………………………………………………….170
Table 7.4 - Comparison between groups on kinetic analysis……………………………………173
Table E.1- Anthropometric, strength and power characteristics in team sport athletes before and after six-weeks of high intensity resistance training……………………………………………………………232
LIST OF FIGURES

Figure 2.1 – Adolescent changes in body mass………………………………..15
Figure 2.2 – Adolescent changes in height…………………………………….15
Figure 2.3 – Action Potential…………………………………………………..37
Figure 2.4 – Neuromuscular feedback mechanisms………………………….41
Figure 2.5 – ATP resynthesis…………………………………………………..42
Figure 2.6 – Four regions of the bench press………………………………..53
Figure 3.1 – Age trends in group fitness……………………………………….81
Figure 3.2 - State male vertical jump…………………………………………..82
Figure 3.3 - Age trends in group fitness………………………………………..84
Figure 4.1 – Within season changes in fitness……………………………..101
Figure 4.2 – Changes in fitness with years in the program………………..102
Figure 5.1 - Gymaware™ optical encoder hardware…………………………120
Figure 5.2 - Typical output from the Gymaware™ software (Example 1)……128
Figure 5.3 – Typical output from the Gymaware™ software (Example 2)……129
Figure 5.4 – Mean bench press power………………………………………..130
Figure 5.5 – Peak power of first phase………………………………………..131
Figure 5.6 – Sticking point low power………………………………………..132
Figure 5.7 – Peak power of third phase………………………………………..133
Figure 6.1 - Comparison of 6RM (kg) in the repetition rest and repetition
failure groups………………………………………………………………150
Figure 6.2 - Comparison of Smith Machine bench throw (W) in the
repetition rest and repetition failure groups…………………………152
Figure 7.1 – Changes in strength and power of different groups…………….171
ACKNOWLEDGEMENTS

When a Ph.D. is completed, the degree is awarded to just one person. Still, there are many people that the completion of the Ph.D. would not have been possible without. These people lend support in professional, technical, and personal ways that allow the work to continue. To all those who have supported me, I would like to extend my gratitude.

I would initially like to extend my thanks to Professor Allan Hahn of the Australian Institute of Sport (AIS). Your idea for the sports-based Ph.D. program at the AIS has changed my life in a wonderful way that never otherwise would have been possible, and for that I will always be grateful. I cannot think of a greater accomplishment than to have such a large impact on another person’s life.

I would also like to thank Associate Professor David Pyne, Australian Institute of Sport. You carefully read each and every proposal and manuscript I presented you with, and provided insight on all of it with an efficiency and clarity that was extraordinary. More than that, you have been a role model to me, teaching me not to accept ‘good enough’ in yourself or your work – that you cannot just keep doing what you have always done to achieve great things. Still more, you would drive me home after basketball games, you taught me to appreciate the finer points of cricket, and showed me the glory of the ‘mixed grill’ at the Central Café. You have been a great supervisor, role model, and friend.

The quality of this work would not have been possible without the critical eye Professor Michael McKenna of Victoria University. Mike, the lessons I have learned from you on how to critically read and write will allow me to excel in any area of academia I choose to explore. Your expressions of “Do it right the first time”, “Stick to your data”, and “Just get straight to your point” continue to resonate in my ears every time I write. You are an inspiration that sport research can still be of the highest scientific calibre, and I hope to be a researcher of your quality some day.

Patrick Hunt of Basketball Australia is one of the most ‘no-nonsense’ people I have ever met. While your door was always open to me Patrick, I knew that any research ideas would have to grab your attention with how it was going to help Australian basketball coaches and players win games. Your demeanour always made me think of the practical applications of any research I wanted to conduct. I will continue to ask the question “So how can this research be used?” for the rest of my academic career.

I would also like to extend my gratitude to the AIS basketball coaches: Marty Clarke, Paul Gorris, Phil Brown, Deb Cook, and Frank Arsego. While often dubious of what a sport scientist could possibly contribute, I greatly appreciate your faith in letting me try new ideas anyway. Similarly, I recognize that my subjects, the AIS basketball players, would much rather have been playing basketball, sleeping, or eating rather than testing on the court, in the gym, or in the laboratory. Still, you performed all testing to the best of your ability simply because I asked you to.

For teaching me that “If it isn’t broken, break it”, I would like to extend sincere thanks to Professor Will Hopkins, Auckland University of Technology. Will, clearly the statistical methods I learned from you played an invaluable role in interpreting the
results all studies of this thesis, but I have learned so much more from you than just the mechanics of statistical analysis and interpretation. I have learned from you that the joy of academia is in interacting with colleagues that can also become your friends. Also, you have taught me that “Life is just too short for bad coffee.”

Finally, I would like to thank Associate Professor Frank Marino who gave an academic job to this rather odd Canadian on faith that I would finish the Ph.D. sooner rather than later. While somewhat later than expected, it is finally done.

To simply write ‘thank you’ to Jennifer, my wife for the duration of this Ph.D., does not seem sufficient for the support you gave me on a daily basis. Jen, I’m sorry that our marriage did not survive to see the end of this process since you were such a large part of it.

I would like to dedicate this thesis to my late father, John, and my mother, Sarah. This thesis stands as a monument to your life-long dedication to my education. From you I learned that effort and persistence leads to success, and if you keep trying you’ll eventually reach your goal. I hope you are proud of this monument that I have built.
Basketball is a sport with many complex demands that require a combination of fitness, skills, team tactics and strategies, and motivational aspects. However, key areas that are likely to play an important role in a basketball player’s success are muscular strength, fitness, and body size. Methods of evaluating and developing these characteristics have been extensively tested in controlled research settings, but there is a dearth of research exploring the value of, and methods of improving, muscular strength, fitness, and body size of basketball players within the demanding schedule of an elite junior development program. These were therefore explored in this thesis.

**Study 1** Concerns about the value of physical testing and apparently declining test performance in junior basketball players prompted a retrospective study of trends in anthropometric and fitness test scores related to recruitment age and recruitment year. Players were 1011 females and 1087 males entering Basketball Australia’s State and National programs (1862 and 236 players respectively). Players were tested on 2.6 ± 2.0 (mean ± SD) occasions over 0.8 ± 1.0 y. Test scores were adjusted to recruitment age (14-19 y) and recruitment year (1996-2003) using mixed modeling. Effects were estimated by log transformation and expressed as standardized (Cohen) differences in means. National players scored more favorably than State players on all tests, differences being generally small (standardized differences, 0.2 – 0.6) or moderate (0.6 – 1.2). On all tests, males scored more favorably than females, with large standardized differences (>1.2). Athletes entering at age 16 performed at least moderately better than athletes at 14 y on most tests (standardized differences, 0.7 - 2.1), but test scores often plateaued, or began to deteriorate when entering at ~17 y. Some fitness scores deteriorated over the 8-y period (1996-2003), most notably a moderate increase in sprint time and moderate (National male) to large (National
female) declines in shuttle-run performance. Variation in test scores between National players was generally less than that between State players (ratio of SD, 0.83 - 1.18). More favorable means and lower variability in higher-level athletes highlights the potential utility of these tests in junior basketball programs, though secular declines in fitness should be a major concern for Australian basketball coaches.

**Study 2** These findings prompted further investigation into the magnitude of changes in individual player fitness and anthropometric test scores between phases of a year and over multiple years. Detailed information on the direction and magnitude of training-induced changes in fitness in a within-subject design is essential for basketball coaches to evaluate and prescribe conditioning programs. Mixed modeling was used to estimate mean changes within and between seasons, and to estimate individual variability as the standard deviation of change scores between assessments. Changes were expressed as standardized (Cohen) effect sizes for interpretation of magnitudes (trivial <0.2; small 0.2-0.6, moderate 0.6-1.2). In the first 2 y National and State males showed small longitudinal improvements in body mass, skinfolds, and shuttle-run performance (effect size 0.28 – 0.42). After 2 y National females made small improvements in most tests (0.27 – 0.42), but National males showed a small decline in shuttle-run performance (0.55). Other changes in mean test scores within and between seasons were trivial. Individuals showed small to moderate variability about the mean change between phases (0.23 – 0.87) and between years (0.26 – 1.03), with State-level players having greater variation in all tests (State/National ratio 1.1 – 2.4). Coaches or sport scientists monitoring or modifying fitness of basketball players should recognize there is generally little overall change in mean fitness within and between seasons. They should also take into account the small to moderate changes in individuals. While fitness training programs for athletes with dedicated needs are
relatively well supported in the literature, there is very limited peer-reviewed literature to assist the resistance training coach in developing body size, strength, and power of team-sport athletes.

**Study 3** Most high-level basketball players participate in an organised resistance training program to improve muscular strength, fitness, and body size. Bench press is one of the most commonly performed resistance training exercises, and there are many different training philosophies revolving around manipulation of different components of the bench press mechanics. During the concentric movement of the bench press, there is an initial high-power push after chest contact, immediately followed by a characteristic area of low power, the so-called “sticking region”. During high-intensity lifting, this decline in power can result in a failed lift attempt. The purpose of this study was firstly to determine the validity of an optical encoder to measure power, and secondly to employ this device to determine power changes during the initial acceleration and “sticking region” during fatiguing repeated bench presses. Twelve highly trained junior basketball players performed a free-weight bench press, a Smith Machine back squat, and a Smith Machine 40 kg bench press throw for power validation measures. All barbell movements were simultaneously monitored using videography and an optical encoder. Eccentric and concentric mean and peak power were calculated using time and position data derived from each method. Validity of power measures between the video (criterion) and optical encoder scores were evaluated by standard error of the estimate (SEE) and coefficient of variation (CV). Seven subjects then performed four sets of six bench press repetitions progressively increasing from 85 to 95% of their 6 repetition maximum, with each repetition continually monitored by an optical encoder. The power SEE ranged from 3.6 to 14.4 W (CV, 1.0-3.0%; correlation, 0.97-1.00). During the bench press training,
peak power declined by ~50% (p<0.05) during the initial acceleration phase of the final two repetitions of the final set. While decreases in peak power of the sticking point were significant (p<0.05) as early as repetition six (~42%) they reached critically low levels in the final two repetitions (~ -95%). In conclusion, the optical encoder provided valid measures of kinetics during free-weight resistance training movements. The decline in power during the initial acceleration phase appears a factor in a failed lift attempt in the sticking point in highly trained junior basketball players.

**Study 4** The power loss in the first phase of the bench press only becomes a limiting factor when the loss of power in the sticking point leads to lift failure. Therefore, training to the point of failure may be an important stimulus for generating sufficient power in the first phase of the bench press to successfully press through the sticking point. This study investigated the importance of training leading to repetition failure in optimising the performance of elite junior athletes in two different tests: six-repetition maximum (6RM) bench press strength and 40kg bench throw power.

Subjects were 26 elite junior male basketball (n=12, age 18.6 ± 0.3 y, height 202.0 ± 11.6 cm, mass 97.0 ± 12.9 kg) and soccer (n=14, age 17.4 ± 0.5 y, height 179.0 ± 7.0 cm, mass 75.0 ± 7.1 kg) players with a history of greater than six months strength training. Subjects were initially tested twice for 6RM bench press mass and 40kg Smith Machine bench throw power output (W) to establish retest reliability. Subjects then undertook bench press training three sessions per week for six weeks, using equal volume programs (24 total repetitions x 80-105% 6RM in 13 min 20 s). Subjects were assigned to one of two experimental groups designed to either elicit repetition failure with four sets of six repetitions every 260 s (RF4x6) or allow all repetitions to be completed with eight sets of three repetitions every 113 s (NF8x3). The RF4x6 treatment elicited substantial increases in strength (7.3 ± 2.4kg, +9.5%,
p<0.001) and power (40.8 ± 24.1 W, +10.6%, p<0.001), while the NF8x3 group elicited 3.6 ± 3.0kg (+5.0%, p<0.005) and 25 ± 19.0 W increases (+6.8%, p<0.001). The improvements in the RF4x6 group were significantly greater than the repetition rest group for both strength (p<0.01) and power (p<0.05). Bench press training that leads to repetition failure induces greater strength gains than non-failure training in the bench press exercise for elite junior team sport athletes.

**Study 5** Strength improvements are greater when resistance training continues to the point where the individual cannot perform additional repetitions (i.e. repetition failure). Performing additional forced repetitions after the point of repetition failure to further increase the set volume is a common resistance training practice. However, whether increasing the number of forced repetitions increases the magnitude of strength development is unknown and was investigated here. Twenty two team-sport athletes trained for six weeks completing either 4x6, 8x3, or 12x3 (sets x repetitions) of bench press. The 4x6 and 12x3 protocols increased the number of forced repetitions by respectively increasing work intervals or volume compared to the 8x3 group. Subjects were tested on 3- and 6-repetition maximum (RM) bench press (81.7±9.9 and 76.2±9.2 kg respectively, mean ±SD), and 40kg Smith Machine bench press throw power (756±156 W). The 4x6 and 12x3 groups had more forced repetitions per session (p<0.01) than the 8x3 group (4.4±0.9 and 3.6±0.8, and 2.0±0.5 repetitions). As expected, all groups improved 3RM (4.6 kg, 95% Confidence Limits: 3.2-6.1), 6RM (4.9 kg, 3.3-6.5), bench throw peak power (59 W, 23-95), and mean power (23 W, 4-42) (all p<0.01). There were no significant differences in strength or power gains between groups. In conclusion, when repetition failure was reached, neither additional forced repetitions, nor additional set volume further improved the
magnitude of strength gains. This finding questions the efficacy of these current
commom strength training practices.

**Conclusions** The quality of key fitness and anthropometric test scores of Australian
junior basketball players showed evidence of decline over a 7 yr study period despite
the importance of fitness and body composition to basketball. Fortunately, there is
sufficient individual variation in changes in fitness and anthropometry test scores to
indicate that substantial improvements are possible with an appropriate training
program. As a method of improving fitness, the bench-press resistance training model,
consisting of two separate six-week training programs equal in volume and training
time but differing in the amount of fatigue, showed that training to the point of
repetition failure elicited greater strength adaptations than non-failure training.
Refinement of the training protocol allowed further comparison of the effects of
additional training volume and a greater number of forced repetitions. Taken together
these experimental findings support the notion that training to the point of repetition
failure is an important component of a periodized training program for strength
development. However six weeks of training using forced repetitions with the
assistance of a spotter conveyed no further benefit to strength, power, or hypertrophic
adaptations. Additional research is required to verify whether the transfer of these
upper body adaptations apply to lower-body activities such as squats, and whether
high intensity short term strength and conditioning programs can improve power
output enough to have a substantial positive impact on basketball-specific skills such
as running and jumping.