

The Acute Effects of Creatine Monohydrate Loading on Simulated Soccer Performance

Jeremy Williams

*A thesis submitted to the
Auckland University of Technology
in partial fulfilment of the degree of
Master of Health Science 2007*

TABLE OF CONTENTS

TABLE OF CONTENTS.....	II
LIST OF TABLES	V
LIST OF FIGURES	VII
LIST OF APPENDICES	VIII
ACKNOWLEDGEMENTS.....	IX
DEDICATION.....	XI
ATTESTATION OF AUTHORSHIP	XII
GLOSSARY	XIII
INTELLECTUAL PROPERTY RIGHTS	XV
ABSTRACT	XVI
CHAPTER ONE: INTRODUCTION	1
INTRODUCTION.....	1
AIMS.....	4
HYPOTHESES	4
CHAPTER TWO: REVIEW OF THE LITERATURE.....	5
2.1 CREATINE MONOHYDRATE	5
2.1.1 Background: What is creatine monohydrate?	5
2.1.2 Side-Effects.....	6
2.1.3 Physiology of creatine.....	6
2.1.4 Creatine supplementation and dosage.....	8
2.1.5 Creatine and Sport.....	11

2.2 SPORTS PERFORMANCE AND CREATINE	14
2.3 SOCCER PERFORMANCE	22
2.3.1 <i>Physical demands of soccer</i>	22
2.3.2 <i>Walking and running movements of soccer</i>	23
2.3.3 <i>Distance covered</i>	24
2.3.4 <i>Tackling and heading movements</i>	25
2.3.5 <i>Aerobic performance</i>	26
2.4 SOCCER PERFORMANCE AND CREATINE	27
2.5 SOCCER / INTERMITTENT SPORTS PERFORMANCE TESTS	34
2.5.1 <i>Soccer simulation protocols</i>	34
2.5.1.1 <i>Lab-based soccer simulation protocols</i>	34
2.5.1.2 <i>Field-based soccer simulation protocols</i>	37
2.5.2 <i>Other team sport protocols</i>	40
2.5.3 <i>Conclusion</i>	46
CHAPTER THREE: METHODS	47
3.1 EXPERIMENTAL DESIGN	47
3.2 SUBJECTS	47
3.3 TEST PROTOCOLS	48
3.4 EQUIPMENT	54
3.5 STUDY ONE: THE RELIABILITY AND VALIDITY OF THE BEAST.....	57
3.5.1 <i>Determination of the VO₂–HR relationship and VO_{2max}</i>	59
3.6 STUDY TWO: THE EFFECTS OF ACUTE CR SUPPLEMENTATION ON SOCCER PERFORMANCE	60
3.6.1 <i>Supplementation administration</i>	60
3.7 STATISTICAL ANALYSIS	61
CHAPTER FOUR: RESULTS	64
4.1 STUDY ONE: RELIABILITY AND VALIDITY OF THE BEAST	64
4.1.1 <i>Reliability</i>	64
4.1.2 <i>Validity</i>	68
4.2 STUDY TWO: THE EFFECT OF ACUTE CR SUPPLEMENTATION ON SOCCER PERFORMANCE	70
4.2.1 <i>Baseline characteristics of the study participants</i>	70
4.2.2 <i>BEAST performance measures</i>	72

4.2.2.1 Mean circuit time	72
4.2.2.2 Mean 12 m sprint time	73
4.2.2.3 Mean 20 m sprint time	74
4.2.2.4 Mean vertical jump height	76
4.2.2.5 Effect sizes and practical assessments of the effect of Cr (relative to placebo) on performance measures	77
4.2.3 Other measures	79
4.2.3.1 Mean heart rate.....	79
4.2.3.2 Mean body-mass	80
4.2.3.3 Mean VO_{2max}	81
CHAPTER FIVE: DISCUSSION.....	82
5.1 STUDY ONE: RELIABILITY AND VALIDITY OF THE BEAST	82
5.1.1 Reliability.....	82
5.1.2 Validity.....	88
5.2 STUDY TWO: THE EFFECT OF ACUTE CR SUPPLEMENTATION ON SOCCER PERFORMANCE	96
5.2.1 Baseline.....	96
5.2.2 Interval main effects.....	96
5.2.3 Trial main effects	98
5.2.4 Group differences.....	98
5.2.5 Clinical significance	103
5.3 LIMITATIONS	105
5.4 CONCLUSION	108
REFERENCES.....	110

LIST OF TABLES

TABLE 1: <i>DOSAGE RANGE FOR SHORT- TERM AND LONG-TERM CREATINE SUPPLEMENTATION STUDIES</i>	10
TABLE 2: <i>ACUTE SHORT-TERM CREATINE INGESTION AND PERFORMANCE STUDIES</i>	19
TABLE 3: <i>ACUTE SHORT-TERM CREATINE INGESTION AND SOCCER PERFORMANCE</i>	33
TABLE 4: <i>SOCCER AND INTERMITTENT TEAM SPORTS PERFORMANCE PROTOCOLS</i>	43
TABLE 5: <i>PARTICIPANT DESCRIPTIVE CHARACTERISTICS. VALUES ARE MEAN \pm SD</i>	48
TABLE 6: <i>TEST-RETEST RELIABILITY VALUES FOR THE BEAST PROTOCOL (TRIAL 1 VERSUS TRIAL 2)</i>	66
TABLE 7: <i>MEAN AND PEAK HEART RATE (HR) AND VO₂ VALUES FOR THE FIRST HALF, SECOND HALF AND FULL 90 MINUTES OF BEAST PROTOCOL FOR TRIAL 2</i>	69
TABLE 8: <i>MEAN (\pm SD) BASELINE VALUES OF THE YO-YO AND VO_{2MAX} PROTOCOL FOR THE TWO STUDY GROUPS</i>	70
TABLE 9: <i>MEAN (\pm SD) TRIAL 2 (BASELINE) VALUES OF THE BEAST VARIABLES FOR THE TWO STUDY GROUPS</i>	71
TABLE 10: <i>EFFECT OF CREATINE (RELATIVE TO PLACEBO) ON PERFORMANCE MEASURES OF THE 90 MINUTE BEAST TEST EXPRESSED IN COHEN UNITS. CONFIDENCE LIMITS, CHANCES THAT THE TRUE EFFECTS WERE SUBSTANTIAL AND PRACTICAL ASSESSMENTS OF THE EFFECTS ARE ALSO SHOWN.</i>	78
TABLE 11: <i>EFFECT OF CREATINE (RELATIVE TO PLACEBO) ON PERFORMANCE MEASURES OVER THE SECOND HALF (45 MIN INTERVAL) OF THE BEAST TEST EXPRESSED IN COHEN UNITS. CONFIDENCE LIMITS, CHANCES THAT THE TRUE EFFECTS WERE SUBSTANTIAL AND PRACTICAL ASSESSMENTS OF THE EFFECTS ARE ALSO SHOWN.</i>	79
TABLE 12: <i>SUBJECTS MEAN (\pm SD) BODY-MASS VALUES (KG) PRIOR TO, DURING AND FOLLOWING BEAST TRIALS 2 AND 3</i>	80
TABLE 13: <i>NOISE, SIGNAL AND NOISE / SIGNAL RATIO FOR ALL SEVEN FULL-TIME (90 MIN) AVERAGED BEAST VARIABLES</i>	86
TABLE 14: <i>RELIABILITY OF SOCCER SIMULATED PERFORMANCE PROTOCOLS</i>	87
TABLE 15: <i>DISTANCES COVERED AND THE PHYSIOLOGICAL LOAD OF DIFFERENT INTERMITTENT TEAM PERFORMANCE TESTS AND GAME SIMULATION PROTOCOLS.</i>	94
TABLE 16: <i>EFFECT OF CREATINE (RELATIVE TO PLACEBO) ON PERFORMANCE MEASURES OF THE 90 MINUTE BEAST TEST EXPRESSED IN COHEN UNITS. CONFIDENCE LIMITS,</i>	

CHANCES THAT THE TRUE EFFECTS WERE SUBSTANTIAL AND PRACTICAL ASSESSMENTS OF THE EFFECTS ARE ALSO SHOWN.	131
TABLE 17: <i>EFFECT OF CREATINE (RELATIVE TO PLACEBO) ON PERFORMANCE MEASURES OVER THE SECOND HALF (45 MIN INTERVAL) OF THE BEAST TEST EXPRESSED IN COHEN UNITS. CONFIDENCE LIMITS, CHANCES THAT THE TRUE EFFECTS WERE SUBSTANTIAL AND PRACTICAL ASSESSMENTS OF THE EFFECTS ARE ALSO SHOWN.</i>	131

LIST OF FIGURES

FIGURE 1: <i>SCHEMATIC ILLUSTRATING THE COMBINED STUDY DESIGN AND TIME LINE</i>	48
FIGURE 2: <i>BALL-SPORTS ENDURANCE AND SPRINT TEST (BEAST)</i>	50
FIGURE 3: <i>SCHEMATIC DESIGN OF THE BEAST PROTOCOL</i>	51
FIGURE 4: <i>SCHEMATIC ILLUSTRATING STUDY ONE (RELIABILITY) DESIGN AND TIME LINE</i>	58
FIGURE 5: <i>MEAN (± 1 SD) 15-MINUTE INTERVAL CIRCUIT TIMES DURING THE BEAST PROTOCOL PRE AND POST-TEST FOR BOTH THE CREATINE AND PLACEBO GROUPS</i>	73
FIGURE 6: <i>MEAN (± 1 SD) 15-MINUTE INTERVAL 12 M SPRINT TIMES DURING THE BEAST PROTOCOL PRE AND POST-TEST FOR BOTH THE CREATINE AND PLACEBO GROUPS</i>	74
FIGURE 7: <i>MEAN (± 1 SD) 15-MINUTE INTERVAL 20 M SPRINT TIMES DURING THE BEAST PROTOCOL PRE AND POST-TEST FOR BOTH THE CREATINE AND PLACEBO GROUPS</i>	75
FIGURE 8: <i>MEAN (± 1 SD) 15-MINUTE INTERVAL VJ VALUES DURING THE BEAST PROTOCOL PRE AND POST-TEST FOR BOTH THE CREATINE AND PLACEBO GROUPS</i>	77
FIGURE 9: <i>MEAN (± 1 SD) PRE AND POST-TEST $VO_{2\text{MAX}}$ SCORES FOR THE CREATINE AND PLACEBO GROUPS</i>	81
FIGURE 10: <i>MEAN (± 1 SD) HR VALUES EACH HALF OF THE BEAST PROTOCOL PRE AND POST-TEST FOR BOTH THE CREATINE AND PLACEBO GROUPS</i>	130

LIST OF APPENDICES

APPENDIX 1: PARTICIPANT INFORMATION SHEET	121
APPENDIX 2: PARTICIPANT CONSENT FORM.....	124
APPENDIX 3: ETHICS APPROVAL SHEET	125
APPENDIX 4: INTERMITTENT SPORT PERFORMANCE TESTS	127
APPENDIX 5: PERFORMANCE TASKS AT EACH STATION OF THE BEAST	128
APPENDIX 6.....	130
APPENDIX 7.....	131

ACKNOWLEDGEMENTS

I would like to express my appreciation to the many individuals who have contributed towards the completion of this thesis:

To Dr Andrew Kilding. Thank you so much for taking me on board as a Masters Thesis student. If it wasn't for your great ideas and enthusiasm over the last two years I don't know where I would be today.

To Dr Grant Abt. Thank you for letting me modify your BEAST protocol, for your great resources and your help with all things soccer related.

To Maynard Williams. You are truly a great statistician; your knowledge in research is astounding. You have helped me when I was down and you did not let me give up, thanks for believing in me dad!

To Jamie Denton, Nick Stone, Jordan McIntyre, MASH, Lisa McKay, Claire Svendsen and Leon Iusitini. Thank you for making the University environment a fun place to work, and sometimes fool around!

To my beautiful fiancée Rose. Thank you for putting up with my bad moods when I was stressed and tired, and for lending a helping hand during data collection as well as being the most supportive and loving person in the world.

To my mum Sonja. Thank you for all your great ideas and input over the last couple of years, you have helped me out more than you think.

To all the BSR co-op students who gave their sleeping time and energy to assist me with data collection.

To all the Takapuna A.F.C first, reserves and third division participants in this study. Thank you all very much for your time, dedication, hard work and commitment that you put into each testing session.

To the coaches and managers at Takapuna A.F.C. Thank you so much for lending me your players for this study. If it was not for you guys, this study would not have happened.

I would also like to acknowledge the Auckland University of Technology for providing the funding needed to undertake this research.

Ethical approval for this research was provided by the Human Subject Ethics Committee of the Auckland University of Technology, 25 September 2005 – ethics approval number 05/179.

DEDICATION

This thesis is dedicated to my fiancée and parents for their constant love and support throughout the last six years of my studies. If it was not for my mum and dad believing in me and encouraging me (persistence is the key, right dad?), I do not think I could have completed this thesis. So above all, I dedicate this to them.

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgment is made in the acknowledgments.

Signed.....

Date.....

GLOSSARY

The following terms are used throughout this thesis:

Adenosine Triphosphate	A high-energy phosphate compound from which the body derives its energy (Wilmore & Costill, 1996).
Creatine	A substance found in the skeletal muscles, most commonly in the form of phosphocreatine (PCr). Creatine supplements are often used as ergogenic aids as they are theorised to increase PCr levels, thus enhancing the ATP-PCr energy system by better maintaining muscle ATP levels (Wilmore & Costill, 1996).
Ergogenic aids	A substance or phenomenon that can improve athletic performance (Wilmore & Costill, 1996).
Intermittent exercise	Exercise that is not continuous in nature, made up of “stop-start” activities.
Phosphocreatine	An energy-rich compound that plays a critical role in providing energy for muscle action by maintaining ATP concentration (Wilmore & Costill, 1996).

$\text{VO}_{2\text{max}}$

Otherwise known as “maximal oxygen uptake”. It is measured during exercise. The maximal amount of oxygen consumed reflects the body’s ability to utilise oxygen as an energy source.

INTELLECTUAL PROPERTY RIGHTS

This thesis may be utilised for the purpose of research or private study provided that due acknowledgment is made where appropriate and that the author's written permission is obtained before any material from the thesis is published.

I agree that the Auckland University of Technology Library may copy this thesis, in electronic or photocopied form, to supply the collection of other libraries on request from those libraries. I also agree that this thesis may be photocopied for supply to any person in accordance with the provision of Section 56 of the Copyright Act 1994.

ABSTRACT

Background. Athletes who participate in sports where performance relies on repeated high-intensity efforts could benefit from creatine (Cr) ingestion due to an increased ability to perform and recover from high-intensity exercise bouts either during training or competition. However, few studies exist which have investigated the effects of acute short-term Cr supplementation on appropriately simulated soccer-specific performance.

Aims. To determine the reproducibility of a 90 minute soccer-specific performance test and to subsequently examine the effects of acute short-term Cr ingestion (1 week) on soccer-specific physical performance.

Study design. Two experimental designs were adopted for this thesis. For study one, a test-retest design was used to determine the reliability and validity of the Ball-sport Endurance And Sprint Test (BEAST). Two trials of the BEAST were performed, separated by five to seven days. For study two, a randomised, triple-blind, placebo-controlled experimental design was adopted to determine the efficacy of acute short-term Cr supplementation (seven days) on soccer-specific performance, using the BEAST protocol.

Methods. Twenty male amateur soccer players volunteered to participate in the study. For study one, the test-retest reliability of several soccer-specific performance measures obtained during a modified version of the BEAST was quantified using the standard error of measurement (Van Cutsem, Duchateau, & Hainaut) (or typical error) (Hopkins, 2000), coefficient of variation (CV), and Intraclass Correlation Coefficient (ICC). For study two, the cohort was split and subjects randomly allocated to one of two groups (Cr supplementation and Placebo) on a matched-pair basis. The Cr group (mean age 25.4 ± 4.5 years, mean body-mass 79.3 ± 10.5 kg) ingested 20 g of Cr and 8 g of glucose powder per day for seven days, whereas the placebo (mean age 26.7 ± 4.6

years, mean body-mass 80.8 ± 8.6 kg) group ingested 20 g of corn-flour and 8 g of glucose per day for seven days. The effects of acute short-term Cr supplementation were analysed by repeated measures ANOVA. In addition, effect sizes (ES) were calculated and entered with the associated p-value into Hopkins' spreadsheet for determination of the ES confidence limits (95%) and the chances that the true effect was substantial (i.e. $ES \geq 0.2$). Clinical/practical inferences were made accordingly.

Results. Study 1: The BEAST protocol had good reliability (high ICC values, relatively low coefficients of variation, low noise to signal ratios) and face validity (HR, VO_2 , distances covered, duration, and movements performed in the BEAST were all similar to those reported in actual soccer matches). Study 2: Performance of the four major physical measures (12 m sprint, 20 m sprint, circuit time and vertical jump) during the BEAST deteriorated during the second half relative to the first half for both Cr and placebo groups, indicating a fatigue effect associated with the protocol. HR and body-mass values also decreased for both groups during the 90 minute protocol. However, there was no statistically significant differences between the groups for these four measures or for body-mass, HR or VO_{2max} values, suggesting Cr had no substantial effect (relative to placebo) on improving physical performance (or reducing fatigue). When the effects were assessed for the whole 90 minute BEAST protocol, all effects showed a negative trend and, correspondingly, the chances of a detrimental effect were greater than the chances of a beneficial effect.

Conclusions: The 90 minute BEAST protocol had good reliability and face validity making it a suitable soccer simulation and performance protocol with which to investigate the effects of Cr supplementation on soccer performance. However, no significant (statistical or clinical) effects of acute short-term Cr supplementation on soccer performance were observed suggesting its potential use as an ergogenic aid for soccer players is questionable.

CHAPTER ONE: INTRODUCTION

INTRODUCTION

Many athletes use sporting ergogenic aids to improve both the quality and quantity of their training and in turn boost their performance in competitive situations (Sundgot-Borgen, Berglund, & Torstveit, 2003). It is possible that additional nutrients may be necessary for athletes during high-intensity exercise to allow for maximal expression of endurance and strength gains (Nissen & Sharp, 2003). Indeed, under specific conditions, sporting ergogenic aids may have positive effects on athletic performance, body composition, and strength (Beduschi, 2003).

Given the multiple demands of team sports (e.g. repeated high-intensity sprints and jumps, sometimes with short recovery periods over long durations ~70-90 min), athletes participating in such sports may benefit from the consumption of nutritional ergogenic aids. One such aid that has gained popularity in recent years is creatine monohydrate (Cr). Creatine is a naturally occurring compound derived from amino acids and is found primarily in the skeletal muscle. Creatine exists in muscles as phosphocreatine (PCr), providing the high-energy phosphate for adenine diphosphate (ADP) to restore adenine triphosphate (ATP) concentration rapidly via the Cr kinase (CK) reaction (Clarkson, 1996). Creatine can be ingested from natural exogenous sources such as fish or red meat, ingested through supplementation, and produced endogenously by the body (Bemben & Lamont, 2005). The average Cr concentration [Cr] in human muscle is approximately 125 mmol·kg⁻¹ dm, but with Cr supplementation (7 days loading) it has been reported to increase the total [Cr] in the muscle by 20 to 50% (Ahmun, 2005; Hultman, Soderlund, Timmons, Cederblad, & Greenhaff, 1996).

To date, researchers have documented beneficial effects of both chronic (>4 weeks) and acute (2 to 7 days) Cr supplementation on strength (Bemben, Bemben, Loftiss, & Knehans, 2001), power (Ahmun, 2005) and speed (Aaserud, Gramvik, Olsen, & Jensen, 1998) in athletes. Most scientific support for the use of Cr is to improve performance related to events requiring high anaerobic power, therefore a large proportion of research on Cr has focused on resistance training interventions.

It is commonly known that athletes involved in intermittent team sports are required to repeatedly produce high-intensity bouts of exercise over the duration of a game. The ability to produce and recover from these maximal explosive efforts (sprints, jumps etc) is likely to be an important contributing factor to the outcome of a game. Soccer players are required to produce high power outputs and maintain or repeat them with only a few seconds recovery (Reilly & Williams, 2003a). Given the physical demand of soccer, it is of interest as to whether these athletes involved in repeated bouts of high-intensity exercise would benefit from acute Cr supplementation. It seems reasonable to suggest that highly trained athletes who play sports by which performance relies on repeated all-out maximal efforts could benefit from Cr through means of an increased ability to perform and recover from intermittent explosive exercise bouts during competition and training. However, few studies exist which have investigated the effects of acute Cr supplementation on soccer performance, especially those using an appropriate soccer simulation protocol (Cox, 2002). Many soccer protocols have been designed but have failed to adequately simulate the physical demands of the game. It seems logical that when assessing soccer performance, the protocols employed need to be specific to the demands and activity patterns (sprinting, turning, jumping, shooting etc) found during a soccer match. Soccer performance cannot be properly assessed by

simply testing performance as separate activities (e.g. sprinting, jumping etc) measured in isolation from one another. Although there have been many team sport simulation protocols developed over the years, there have been none that have completely replicated the intensity, duration, distance, ball-skill work, movement patterns and general soccer skills that are required in a soccer game. If a performance protocol is inadequate in duration and does not replicate the activity patterns and demands of a soccer match, it becomes very difficult to determine whether there have been any effects from a training or nutritional intervention on a soccer players' entire 90 minute performance. Therefore, a closely-controlled, sport-specific soccer simulation protocol that reflects the most recent analysis of soccer match-play will help accurately determine the potential performance enhancing effects of acute Cr supplementation. Thus while, the aim of this thesis was to determine the acute effects of Cr supplementation on simulated soccer performance, a secondary aim was to develop a reliable and valid soccer-specific protocol that replicates most demands of an actual soccer game. To this end, the Ball-sports Endurance And Sprint Test (BEAST) (Abt, 2006) was first modified and its reliability and validity determined.

AIMS

The aim of this study is two-fold: 1) to design and determine the reproducibility and validity of a soccer-specific performance test (BEAST), and 2) to determine the effects of acute short-term creatine (Cr) ingestion (1 week) on soccer performance (using the BEAST as a measure of performance).

HYPOTHESES

It is hypothesised that the devised soccer performance test will have acceptable reliability and face validity. It is also hypothesised that soccer performance will significantly improve for the group of subjects after ingesting Cr for seven days.

CHAPTER TWO: Review of the Literature

2.1 CREATINE MONOHYDRATE

2.1.1 Background: What is creatine monohydrate?

Creatine (Cr) or methyl guanidine-acetic acid, is a naturally occurring compound derived from the amino acids glycine, arginine and methoionine (Beduschi, 2003). Creatine monohydrate is one of the most popular sporting supplements in the world today and is used by high-school athletes, the elderly, professional and recreational athletes in the hope of improving physical performance (Bemben & Lamont, 2005). Creatine is a sporting ergogenic aid in the form of a thick white powder that is most commonly consumed by dissolving the substance into a carbohydrate glucose solution in two phases (depending on whether supplementation is acute short-term or chronic long-term); 1) loading phase & 2) maintenance phase. During acute short-term Cr supplementation there is usually only a loading phase, whereas chronic long-term ingestion usually involves a loading phase followed by a maintenance phase. The loading phase involves consumption of a large dose of Cr over five to seven days (approximately 20 to 30 grams·day⁻¹ depending on an individual's body-mass) to “top up” the body's natural Cr stores. After the loading phase, athletes will have to maintain these “topped up” Cr stores by consuming a smaller maintenance dose (approx 2 to 5 grams·day⁻¹) over four to ten weeks. There are a variety of Cr manufacturers, however, according to Hespel, Maughen & Greenhaff (2006), there is no evidence to suggest that so-called “special” Cr formulations are better than simple Cr products. Athletes consuming Cr as a performance enhancing supplement are usually those involved in activities / sports that require considerable strength and power production (i.e. American football players, power-lifters, ice hockey players, boxers etc). Creatine is also used by

athletes to increase lean muscle mass. During Cr supplementation, body-mass gain can range from zero to about 2 kg after five days (Bizzarini & De Angelis, 2004). However, most of this early increase could be due to fluid retention in the muscle cells, as it has been speculated that water retention is involved in the co-transport of Cr and sodium into the muscle fibres (Willott et al., 1999).

2.1.2 Side-Effects

There is no strong evidence in the literature to support any significant side-effects of Cr supplementation either short-term or long-term (Schroder, Terrados, & Tramullas, 2005). There is only anecdotal evidence to suggest muscle cramping and gastrointestinal symptoms, but these cases do not represent well-controlled trials, therefore it cannot be concluded that a well established relationship between Cr and these effects exist. However, whilst an increase in body-mass due to Cr might be considered a positive side-effect for some athletes, it could be considered a negative side-effect for others (i.e. unwanted weight gain may potentially decrease an athlete's performance if they are a long distance runner, endurance swimmer, soccer player or a boxer in a weight division). In the future, the true long-term effects (5+ years) of Cr will become known.

2.1.3 Physiology of creatine

Creatine is found predominantly in the skeletal muscle, and its free and phosphorylated forms play a vital role in the regulation and homeostasis of skeletal muscle energy metabolism (Greenhaff, Bodin, Soderlund, & Hultman, 1994). Creatine exists in muscles as phosphocreatine (PCr), providing the high energy phosphate for adenosine

diphosphate (ADP) to restore adenosine triphosphate (ATP) concentration rapidly via the Cr kinase (CK) reaction (Clarkson, 1996).

Creatine can be ingested from natural exogenous sources such as fish or red meat, ingested through supplementation, and produced endogenously by the body, primarily in the liver (Bemben & Lamont, 2005). Creatine is synthesised in the liver (from two amino acids) by a two step reaction. According to Terjung et al (2000) the first step involves a reaction catalysed by the amino acids arginine and glycine to form guanidinoacetate. In the second step, a methyl group of S-adenosylmethionine is transferred to guanidinoacetate and Cr is formed. Muscle does not synthesise Cr but is dependent on Cr uptake from the circulation by a sodium dependent transporter in the muscle membrane. Once the Cr is in the myocyte, it becomes phosphorylated via the CK reaction and the distribution between Cr and PCr is determined by the energy state of the cell (Terjung et al., 2000).

Creatinine is the end-product of Cr metabolism and is formed by the non-enzymatic conversion from PCr and Cr (approx 2% of total Cr pool per day). This end-product is then excreted by the kidneys (approx 2 grams·day⁻¹ for an adult) which is then passed out in the urine (Terjung et al., 2000; Walker, 1979). This explains why there seems to be a relatively long washout period (~6 weeks) after oral Cr supplementation (Preen, Dawson, Goodman, Beilby, & Ching, 1999).

Creatine supplementation can cause an increase in urinary creatinine excretion (Harris, Soderlund, & Hultman, 1992), which is often used as an indicator of kidney function (Greenhaff, 1997). This observed increase in urinary creatinine correlates well with the

increase in muscle Cr absorbed during Cr supplementation and provides some evidence of the filtering of Cr stores in the body (Hultman et al., 1996).

The average Cr concentration [Cr] in human muscle is approximately $125 \text{ mmol}\cdot\text{kg}^{-1} \text{ dm}$ (range: 90 to $160 \text{ mmol}\cdot\text{kg}^{-1} \text{ dm}$), but with Cr supplementation (7 days loading) it has been reported to increase the total [Cr] in the muscle by 20 to 50% (Ahmun, 2005; Hultman et al., 1996). Walker (1979) suggested a healthy 70 kg man contains approximately 120 g of Cr in muscle and nerve tissues. Ninety five percent of Cr is situated in the skeletal muscles, with 60 to 70% in the form of PCr which is trapped in the cell (Balsom, Soderlund, & Ekblom, 1994). Dietary Cr is absorbed by the intestine, which then enters the bloodstream where it is transported to the brain, liver, skeletal muscle, kidneys and testicular tissue (Greenhaff, 1997).

2.1.4 Creatine supplementation and dosage

There is wide-spread use of Cr supplementation by professional athletes, elite sports competitors, collegiate athletes, amateur and recreational athletes, as well as clinical patients (Terjung et al., 2000). Studies have examined both the acute (short-term) effects of Cr loading of $20 \text{ to } 25 \text{ grams}\cdot\text{day}^{-1}$ for two to seven days (Ahmun, 2005; Bemben et al., 2001; Hoffman, Stout, Falvo, Kang, & Ratamess, 2005; Peyrebrune, Nevill, Donaldson, & Cosford, 1998) as well as the chronic (long-term) effects of a maintenance regimen of $3 \text{ to } 15 \text{ grams}\cdot\text{day}^{-1}$ for 4 to 10 weeks (Bemben et al., 2001; Kreider et al., 1998; Stone et al., 1999; Vandenberghe et al., 1997). Studies that have investigated supplementing the diet with approximately $20 \text{ grams}\cdot\text{day}^{-1}$ of Cr for two to seven days (acute short-term) have shown total Cr levels in the muscle to be elevated by

10 to 20% (Balsom et al., 1994; Green, 1996; Greenhaff et al., 1994). Table 1 illustrates the different Cr loading parameters studies have used.

Table 1: Dosage range for short- term and long-term creatine supplementation studies

Reference	N / Gender	Age	Trained / Untrained	Sport / Event	Loading	Maintenance	Effect
Aeserud et al (1998)	14 M	20.7 yrs	T	Handball	15g/day x5 days	2g/day x9 days	- Delayed onset of fatigue in 40m sprints (from test 1 to test 3 = 22%)
Ahmun et al (2005)	14 M	20.6 yrs	T	Rugby	20g/day x5 days	N/A	-↑ BM (0.4%) -↑ Peak power in (4.9%)
Bemben et al (2001)	25 M	19.4 yrs	T	American Football	20g/day x5 days	5g/day ~9 weeks	-↑ BM (3.8%) -↑ Anaerobic power and capacity (19.6% and 18.4%) -↑ 1RM Bench press (5.2%), power clean (3.8%) and squat (8.7%)
Hoffman et al (2005)	40 M	21.4 yrs	U	Recreationally active	6g/day x6 days	N/A	-Delayed onset of fatigue in sprints
Kreider et al (1998)	25 M	19.9 yrs	T	American Football	15.75g/day x28 days	15.75g/day x28 days	-↑ BM -↑ Bench press lifting volume -↑ Sum of bench press, squat and power clean volume
Peyrebrune et al (1998)	14 M	20 yrs	T	Swimming	9g/day x5 days	N/A	-↓ Total swimming sprint time (2.1%)
Stone et al (1999)	42 M	18.4 yrs	T	American Football	0.22g/kg/day x7 days	0.22g/kg/day x5 weeks	-↑ BM (1.4%) -↑ 1RM Bench press (10%)
Vandenbergh et al (1997)	19 F	20.5 yrs	U	Sedentary	20g/day x4 days	5g/day x10 weeks	-↑ Fat free BM (5.5%) -↑ 1RM Leg press (29.9%), leg extension (46%) and squat (31.4%)

BM = Body-mass, ↑ = Significant increase, ↓ Significant decrease, T = Trained, U = Untrained, M = Males, F = Females, Yrs = Years, RM = Repetition maximum

2.1.5 Creatine and Sport

Most of the scientific support for the efficacy of Cr supplementation is to improve performance related to events / sports requiring high anaerobic power (Branch & Williams, 2002). Thus, a significant proportion of research on Cr has focused on resistance training interventions. Creatine supplementation combined with resistance training has been documented to have a greater increase in strength, (Kreider et al., 1998) and power (Bemben et al., 2001), increased work rate (Kreider et al., 1998), and an increase in body-mass (Vandenberghe et al., 1997) than resistance training alone. Increases in Cr and PCr levels due to supplementation (Hultman et al., 1996) have been shown to enhance sport performance by 1) improving PCr and ATP resynthesis (Greenhaff, 1994), and 2) decreasing muscle relaxation time (Van Leemputte, Vandenberghe, & Hespel, 1999; Vandenberghe et al., 1997). Collectively, these effects potentially allow individuals to train and compete at a higher intensity, which amplifies the adaptation process in muscle.

Athletes involved in intermittent team sports (e.g. soccer, field hockey, rugby etc) are required to repeatedly produce high-intensity efforts (interspersed with recovery of varying duration and intensity) over the duration of a game (70 to 90 min). The ability to recover and to reproduce a maximal power effort in subsequent sprints and jumps is likely to be an important contributing factor to the final outcome in team sport games. However, evidence to suggest this is at present anecdotal (Bishop, 2005). Maintenance of peak muscular force production in short-term, high-intensity exercise tasks (i.e. sprinting, jumping etc) is likely to depend on levels of high-energy phosphagens such as adenosine triphosphate (ATP) and PCr (Redondo, Dowling, Graham, Almada, & Williams, 1996). Due to intramuscular ATP storage being able to sustain muscular

activity for only a few seconds (1 to 2 s), ATP must be continually resynthesised by other sources for muscle activity to continue (Bishop, 2005). It is accepted that the majority of the energy required to resynthesise ATP for a short time period during maximal exercise (~2 to 3 s) is provided by PCr degradation and anaerobic glycolysis (Gaitanos, Williams, Boobis, & Brooks, 1993). Therefore, sprints associated with intermittent team sports (i.e. short sprint periods of ~2 to 3 s) are likely to require considerable amounts of energy via anaerobic glycolysis and PCr degradation.

According to Greenhaff (1997) the availability of PCr is generally expected to be one of the most likely limitations to muscle performance during intense, fatiguing, short-lasting contractions; its depletion resulting in an increase in cellular adenosine diphosphate (ADP) concentration and, thereby, the development of fatigue via an inhibition of muscle cross-bridge formation. Therefore, it is hypothesised that when Cr is ingested by athletes, it supposedly resynthesises ATP at a faster rate (due to the increased PCr stores) within the muscles after intermittent activity (Greenhaff et al., 1993), and this is speculated to improve an individual's ability to recover (e.g. between and after multiple maximal effort sprints). Branch (2003) conducted a meta-analysis of 100 studies (minimum study criteria were: (a) randomised group formation, (b) inclusion of a placebo control, (c) subjects who were blinded to treatments, and (d) dependent measures of body composition and / or physical performance with summary statistics). The study compared the effects of Cr supplementation on effect sizes for body composition variables, duration and intensity of the exercise task and subject characteristics. Findings from this meta-analysis added additional support to the effectiveness of Cr in increasing total and lean body-mass, and performance in high-intensity, short duration repetitive tasks.

Short-term, high-intensity, intermittent exercise presents a significant disruption to homeostasis in skeletal muscle. Among the factors related to fatigue from this type of exercise are 1) the depletion of high-energy phosphagens (ATP, PCr) and 2) the accumulation of undesirable metabolites (Cooke, Petersen, & Quinney, 1997). According to Cooke et al (1997), convenient markers of these two phenomena are the concentration of PCr and intracellular pH, respectively. Though the cause-and-effect relationships are not yet clear, there is sufficient evidence to suggest that depletion of PCr and decreased pH (due to hydrogen ion accumulation) are both associated with the state of fatigue in skeletal muscle, and the decline in muscle power during high-intensity exercise (Cooke et al., 1997). The amount of time it takes for PCr restoration is said to be rapid, with half-times generally reported to be around 30 s (Sahlin, 1992). In contrast, the recovery of muscle pH returning to pre-fatigue levels takes around ten minutes (Metzger & Fitts, 1987), however this could possibly be dependent on the level of decrease in pH during exercise. An increased availability of PCr through supplementation (and a faster PCr rate of recovery) has the potential to increase the intramuscular buffering capacity, and delay the point at which muscle pH reaches a critically low level. Therefore, the rate of recovery for a Cr supplemented athlete should be faster than their opponent; however, this will also depend on the opponent's rate of recovery. It is clear that the faster an athlete can recover from multiple maximal effort sprints, jumps and any other high-intensity activity within a sporting situation, the more of an advantage they will have over their competitors in the final outcome (e.g. being first to the ball to defend a last minute shot on goal, or to jump higher in a corner kick to head the ball into the goal to score).

2.2 SPORTS PERFORMANCE AND CREATINE

Many sports have used Cr as a performance enhancing ergogenic aid. This review will focus primarily on studies that have investigated the effects of acute Cr supplementation.

A review of the studies that have tested the acute effects of Cr on performance in various sporting codes (rugby, tennis, handball, softball, wrestling, swimming, squash, cycling, hockey and ice hockey) are presented in Table 2. Overall, the effect of acute Cr supplementation on performance in different sports appears inconsistent. Specifically, half of the studies (6 / 12 studies) that have investigated the effects of acute short-term Cr supplementation using various sprint performance tests (cycling, running, swimming, ice skating etc) have reported no significant improvement in sprint performance (Ahmun, 2005; Cornish, Chilibeck, & Burke, 2006; Deutekom, Beltman, de Ruiter, de Koning, & de Haan, 2000; Kocak & Karli, 2003; Miszko, Baer, & Vanderburgh, 1998; Pluim et al., 2006; Redondo et al., 1996). Conversely, other studies (6 / 12 studies) *have* found significant improvements in sprint performance, ranging from 1.9% to 14.6% (Grindstaff et al., 1997; Izquierdo, Ibanez, Gonzalez-Badillo, & Gorostiaga, 2002; Kocak & Karli, 2003; Romer, Barrington, & Jeukendrup, 2001; Vandebuerie, Vanden Eynde, Vandenberghe, & Hespel, 1998).

Kocak and Karli (2003) investigated the effects of oral Cr supplementation on 20 elite Turkish wrestlers. Pre-tests and post-tests were conducted on a Monark cycle ergometer, using a Wingate cycle (30 s) protocol. There were significant improvements ($p<0.01$) in both mean (11%) and peak power (14.6%) in the Cr group with no

significant change in the control group. Similarly, Vandebuerie et al (1998) also reported considerable improvements in sprint cycle performance (peak and mean power of 8 to 9%; $p < 0.05$) after five days Cr supplementation in well-trained cyclists. In contrast to these studies, Ahmun, Tong and Grimshaw (2005) recently conducted a randomised control cross-over study on 14 highly trained rugby players. Two tests were administered on separate days; a 10 x 6 s Wingate cycle test and a 10 x 40 m running sprint test. After acute short-term Cr ingestion (5 g Cr x 4 per day for five days), subjects did not significantly improve in running sprints or repetitive and maximal cycling sprints. Similarly, Deutekom et al (2000) did not find any ergogenic effect of Cr on repeated cycle sprint performance (2 x 30 s sprints) after six days supplementation in subjects. The authors of this study noted that it remains “unclear” why positive effects of Cr supplementation have been reported in some studies whereas, using similar cycle protocols, others (including this one) have been unable to demonstrate similar positive results.

Using squash players as subjects, Romer et al (2001) reported that Cr ($0.3 \text{ g} \cdot \text{day}^{-1}$ x five days) improved mean set running sprint time (in 9 / 10 sets) using a squash ghosting protocol (made up of repeated short sprints and turns) by 3.2% ($p < 0.05$). Similarly, Izquierdo et al (2002) reported mean five meter running sprint times (in all 6 x 5 m sprints) to decrease 1.9% ($p < 0.05$) after acute Cr supplementation ($20 \text{ g} \cdot \text{day}^{-1}$ x five days). Although these two studies have illustrated clear significant improvements in repeated sprint performance after acute Cr ingestion, there have been studies that have documented no improvement in running sprint times. Four studies have reported no improvement in repeated running sprint performance (3 x 60 m, 5 x 27 m, 10 x 40 m and 15 x 20 m sprints respectively) after acute, short-term Cr ingestion (Ahmun, 2005;

Miszko et al., 1998; Pluim et al., 2006; Redondo et al., 1996). These findings suggest more research is needed to clarify the true effect of acute short-term Cr supplementation on repeated sprint performance. A potential explanation why no effects were found in sprint performance in some studies is that it is possible not everybody responds to Cr (or general ergogenic aids themselves) in the same way. For example, some athletes may need a longer duration of supplementation (>7 days) as their Cr stores may not be full, whereas other athletes Cr stores might be full after only a few days or at the start of the study. This is dependant on the subject's diet and initial natural Cr levels before supplementation. Three of the four studies (Redondo et al., 1996, Miszko et al., 1998, Ahmun et al., 2005) did not record the subjects' diet or initial Cr levels before the supplementation period; therefore it is unknown how full their Cr stores were initially.

In a recent study by Cornish, Chilibeck, & Burke (2006), 17 competitive male ice hockey players were randomised into either a Cr group (0.30 g.kg⁻¹ Cr mixed with 0.23 g.kg⁻¹ sucrose and 0.23 g.kg⁻¹ corn flour per day for five days) or a placebo group. Subjects performed a skating treadmill test (10 s sprints with 30 s rest until volitional fatigue) and an isokinetic strength test (3 sets of 10 reps of knee flexion and extension at 60 degrees per second) pre and post-supplementation. There were no significant differences between groups in any of the tests post-supplementation. Results of this study were similar to that of Deutekom et al (2000) and Pluim et al (2006). Two performance measures Deutekom et al (2000) used were isokinetic (x 40 isokinetic contractions at 180 degrees.sec⁻¹) and isometric (x 5 maximal contractions) contractions of the quadriceps muscles using a Biodex Multi-Joint System (isokinetic dynamometer) before and after acute Cr supplementation (20 g.day⁻¹ for six days). No differences were found in both isokinetic and isometric measures post-test for the Cr group. Pluim

et al (2006) performed a battery of tests on 36 male tennis players after six days of Cr ingestion (0.3 g.kg^{-1} per day). In accordance with Deutekom et al (2000), no differences were found between groups in either isometric strength tests (bench press and leg press) post-supplementation. However, these findings are in contrast to that of Izquierdo et al (2002), who reported the effects of Cr supplementation on muscle power, endurance and sprint performance in male handball players. Nineteen previously resistance trained male handball players were used and randomly assigned to either a Cr (20 g.day^{-1} for five days) or a placebo group. Specifically, maximal 1RM half squat increased (11.1%), mean sprint time for five meters decreased (1.9%), maximum repetitions of half squat increased (20.5%) and mean power output of half squat (10.1%) and bench press (11.7%) to fatigue increased significantly ($p < 0.05$) in the Cr group post-supplementation, compared to that of the placebo group. These findings indicate that acute short-term Cr supplementation may not have an effect on isometric or isokinetic strength but may have an effect on isoinertial strength. It should be acknowledged that these results are not fully conclusive and the mechanisms explaining these differences are not yet understood, therefore more research is needed.

A commonly reported finding after acute Cr supplementation appears to be an increase in body-mass (0.4 to 1.8%) (Ahmun, 2005; Deutekom et al., 2000; Izquierdo et al., 2002; Kocak & Karli, 2003; McNaughton, Dalton, & Tarr, 1998; Miszko et al., 1998). This is most likely due to water retention (Willott et al., 1999). Results were inconclusive for two studies, as they did not report the subjects post-test body-mass (Romer et al., 2001; Vandebuerie et al., 1998).

In summary, many studies have assessed the effects of acute short-term Cr supplementation on anaerobic performance (sprinting velocity, power etc). However, whilst there seems to be clear evidence that body-mass increases after a few days of Cr supplementation, results are still inconclusive as to whether there are any significant performance enhancing effects in short duration, maximal tasks.

Table 2: *Acute short-term creatine ingestion and performance studies*

Author	Subjects	Protocols / Tests	Dosage	Results
Ahmun et al (2005)	14 M Rugby players (20.6 yrs)	Modified Wingate test on cycle (10 x 6s) & 10 x 40m sprints on indoor track	Cr = 20g/day x5 days Pla = 2g/day dextrose x5 days	-↑ BM inc Cr group (0.4%) -N/C in sprint velocity -N/C in cycle performance
Cornish et al (2006)	17 M Ice hockey players (19.3 yrs)	Skating treadmill test Isokinetic dynamometer	Cr = 0.3g/kg/day with 0.23g sucrose/kg/day and 0.15g flour/kg/day x5 days Pla = sucrose-flour mix	-N/C in skating treadmill test in both groups -N/C in mean power or peak torque in both groups -N/C in BM in both groups
Deutekom et al (2000)	23 M Rowers (23 yrs)	Electrical stimulation Isometric and Isokinetic strength (quads) Cycling -2 x 30s max sprints (4 mins rest)	Cr =20g/day x6 days Pla = 20g/day x6 days (maltodextrin)	-↑ BM inc Cr group (1.8%) -N/C on isokinetic performance -N/C on repeated cycle sprint performance
Grindstaff et al (1997)	18 M/F amateur Swimmers (15.3 yrs)	3 x 100 m freestyle sprints (60s rest) 3 x 20s arm ergometer tests (60s rest)	Cr =21g/day x9 days Pla = 25.2g/day x9 days (maltodextrin)	-N/C in BM -↓ 50m and 100m time in Cr group in Heat 2 (1.9% & 2.4%) -↓ 100m time in Cr group in Heat 2 (3.5%) -N/C in 50m or 100m times for Heat 3

Izquierdo et al (2002)	19 M Handball players (20.8 yrs)	1RM bench press and half squat Max reps bench and squat CMJ Max discontinuous incremental running test Repeated max sprint tests (15m)	Cr = 20g/day x5 days Pla = 20g/day x5 days (maltodextrin)	-↑ BM in Cr group (1%) -↑ 1RM half squat in Cr group (11.1%) -↑ Mean total number of reps to fatigue in bench press (11.7%) and half squat (10.1%) in Cr group -↑ Mean total mean power production in bench press (14 W) and half squat (52 W) in Cr group -↑ CMJ (0.2 cm) in Cr group -↓ Mean sprinting times for 5m in Cr group (1.9%)
Kocak & Karli (2003)	20 M Wrestlers (24 yrs)	Wingate 30 s anaerobic fitness test	Cr = 20g/day x5 days Pla = 20g/day x5 days (milk powder)	-↑ Mean power in Cr group (11%) -↑ Peak power in Cr group (14.6%) -↑ BM in Cr group (1.2%)
McNaughton et al (1998)	16 M Surf Ski and white-water Kayakers (21 yrs)	Kayak ergometer test	Cr = 20g/day x5 days Pla = 20g/day glucose x 5 days	-↑ BM in Cr group (1.0 kg) -↑ Work completed in Cr group
Miszko et al (1998)	14 F Division 1 Softball players (age unknown)	VJ 5 x 27m sprints (1min recovery)	Cr = 25g/day x6 days Pla = 25g/day lactose x 6 days	-N/C in VJ, or sprint performance -↑ BM inc Cr group (1.4%) -↑ BM inc Pla group (1.2%)
Pluim et al (2006)	36 M International Tennis players (22.5 yrs)	Field test Sprint test (15 x 20m) Isometric strength Assessment (bench press and leg press)	Cr = 0.3g/kg.BM/day x6 days Pla = 0.42g/kg.BM/day maltodextrose & 0.12g/kg.BM/day of dextrose	-N/C in BM, bench press and leg press strength, sprinting time, serving velocity or ground stroke velocity

Redondo et al (1996)	18 M/F Soccer and Hockey players (20.5 yrs)	Sprint 3 x 60m	Cr = 25g/day x7 days Pla = 25g/day glucose x7 days	-N/C in BM or running velocity
Romer et al (2001)	9 M Squash players (21.3 yrs)	Ghosting routine	Cr = 0.3g/day x5 days	-↑ Mean sprint time (3.2%)
Vandebuerie et al (1998)	12 M Cyclists (26 yrs)	Endurance cycle (ergometer) & x5 maximal 10s cycle sprints afterwards	Protocol A: Cr = 25/day x5 days	-N/C in endurance -↑ Mean and peak cycle power (8-9%)

BM = Body-mass N/C = No change/differences between groups, ↑ = Significant increase (p<0.05), ↓ = Significant decrease (p<0.05), Cr = Creatine, Pla = Placebo, Wks = Weeks, M = Males, F = Females, Yrs = Years, CMJ = Counter movement jump

2.3 SOCCER PERFORMANCE

Soccer / football is the world's most popular form of sport, being played in every nation without exception (Reilly & Williams, 2003c). A soccer team consists of eleven players on the field per side with three or four players on the "bench" ready to be substituted anytime during the game. A game of soccer lasts at least 90 minutes (with one to ten minutes extra for injury time), and is made up of two 45 minute halves. The halves are separated by a 10 to 15 minute "half-time break" for players to re-hydrate, re-fuel and talk team strategy with their coach(es).

2.3.1 Physical demands of soccer

Soccer players are frequently required to produce high power outputs (e.g. short explosive sprints, jumps etc) and maintain or repeat them with only a few seconds recovery (Reilly & Williams, 2003b). The average exercise intensity for a soccer player in a 90 minute soccer match is close to that of the lactate threshold or 80 to 90% of maximal heart rate (Hoff, 2005). Soccer involves repeated high-intensity, intermittent bouts of exercise, which stress both the aerobic and anaerobic metabolic pathways (Metaxas, 2005). These numerous explosive bursts are essential in soccer for kicking, tackling, turning, sprinting, changing pace and sustaining forceful contractions to maintain balance and control of the ball against pressure from the opposition (Wisloff, Helgerud, & Hoff, 1998). The physiological demands of match-play in soccer have been examined by making observations during game play, obtaining physiological measures during real and simulated games, and determining the physical capacity of elite players on test performance (Bangsbo, Norregaard, & Thorso, 1991).

2.3.2 Walking and running movements of soccer

Research has shown that, among professional soccer players, high-intensity running accounts for 8 to 18% of the total playing time during a soccer match, whereas 70 to 80% is spent walking or running at a low intensity (Bangsbo et al., 1991; Di Salvo et al., 2007; Ekblom, 1986; Reilly & Thomas, 1976; Van Gool, Van Gerven, & Boutmans, 1988; Ziegenfuss, Lemon, Rogers, Ross, & Yarasheski, 1997). Soccer players' locomotion activities have been documented in several studies. Bangsbo, et al. (1991) administered a study on nine full-time male professional soccer players in the first division Danish league and five semi-professional Danish male players in the second division. Match analysis using several videotape recorders and cameras positioned around the soccer field were used. The videotapes were then replayed on a television monitor and were coded for ten match activities and placed into five different categories (standing, walking, low intensity running, high-intensity running and other). The results illustrated the mean time per occurrence the players performed these activities. Over the 90 minute period, players were standing still for 17.1% of the total playing time, walking 40.4% of the total playing time, low intensity running 35.1% of the total playing time and high intensity running 8.1% of the total playing time. It has also been documented in several soccer studies, that sprint bouts occur approximately every 90 s, each lasting on average two to four seconds in duration (Bangsbo et al., 1991; Mayhew & Wenger, 1985; Reilly & Thomas, 1976; Withers, Maricic, Wasilewski, & Kelly, 1982). The number of sprints reported in a soccer game varies greatly from 17 to 62 (Bangsbo et al., 1991; Di Salvo et al., 2007; Mohr, Krstrup, & Bangsbo, 2003). The large variance in the number of sprints performed could be due to many factors (i.e. different game intensities, player skill level, environmental conditions etc). Due to the unpredictable nature of soccer, short periods of repeated sprint activity may be required on several occasions throughout a game. While it is likely that this type of movement

pattern contributes a small proportion to the overall motion activity during soccer, it may be critical to the end result of a game. (Spencer, Bishop, Dawson, & Goodman, 2005).

It has been assumed that a relationship exists between the amount of high-intensity activity performed during a soccer game and the quality of the soccer match-play (Ekblom, 1986). If recovery periods between these bouts of strenuous efforts are inadequate in duration, or if the individual is not properly conditioned, fatigue will result (Reilly, 2005). It is also speculated that the likelihood of scoring in a soccer game is increased during the second half of a match. The underlying mechanism(s) behind reduced exercise performance at the end of a soccer game is unclear (Bangsbo, Mohr, & Krstrup, 2006). However, one popular theory adopted is that the onset of fatigue in long-term intermittent exercise could be primarily caused by low muscle glycogen stores (Balsom, Gaitanos, Soderlund, & Ekblom, 1999). In support, Krstrup et al (2006) undertook histochemical analysis on human muscles fibres, and documented about half of the individual muscle fibres were almost depleted or depleted of glycogen after a soccer match.

2.3.3 Distance covered

The reported distance covered in a 90 minute soccer game varies from 8638 m to 11527 m (Bangsbo & Lindquist, 1992; Bangsbo et al., 1991; Di Salvo et al., 2007; Helgerud, Engen, Wisløff, & Hoff, 2001; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr et al., 2003; Rampinini, Bishop, Marcora, Sassi, & Impellizzeri, 2007; Rienzi, Drust, Reilly, Carter, & Martin, 2000; Thatcher & Batterham, 2004; Van Gool et al., 1988; Withers et al., 1982). The large variance (~3000 m) in match distances could

potentially be due to the different game intensities i.e. the faster the pace of the game the higher the work-rate, therefore the greater distance covered in a game (Rienzi et al., 2000); environmental conditions i.e. the hotter the environment the greater fluid loss and a shorter time to fatigue, therefore potentially less distance covered in a game (Maxwell, Aitchison, & Nimmo, 1996); fitness of players i.e. players with a higher aerobic capacity will tend to have a higher work-rate, therefore will cover greater distances than players with a lower aerobic capacity (Helgerud et al., 2001); the influence of the opponent and their tactics (Carling, Williams, & Reilly, 2007) i.e. the greater the skill level of an opponent, the harder one has to work and therefore potentially increasing their work rate.

Motion analysis studies have reported top-class soccer players to have sprinted, on average, a total distance of 343 m to 771 m (Bangsbo et al., 1991; Di Salvo et al., 2007; Mohr et al., 2003; Rampinini et al., 2007; Van Gool et al., 1988), ran at moderate to high-intensity a total distance of 788 m to 1536 m (Bangsbo et al., 1991; Di Salvo et al., 2007; Rampinini et al., 2007; Thatcher & Batterham, 2004) and ran at low intensity (jogged) a total distance of 3650 to 5207 m (Bangsbo et al., 1991; Rienzi et al., 2000; Thatcher & Batterham, 2004) during a real soccer match.

2.3.4 Tackling and heading movements

Soccer players perform on average 10 to 19 tackles and 9 to 13 headers during a match, most of which involve jumping for aerial possession of the soccer ball (Bangsbo et al., 1991; Ekblom, 1986; Van Gool et al., 1988; Ziegenfuss et al., 1997). Many activities in soccer are forceful and explosive. The large power output generated during such activities is related to the absolute strength of the muscles involved in the movements

(Reilly, Bangsbo, & Franks, 2000). It has been acknowledged that strong quadriceps, hamstrings, triceps surae, hip flexors, ankle dorsi-flexors and ankle plantar-flexors can potentially be beneficial for soccer-specific activities such as jumping, kicking, changing pace or direction, tackling, and maintaining balance (Shephard, 1999), although there is still a great deal of conjecture over the inter-relationship between strength, power and functional performance.

2.3.5 Aerobic performance

It is estimated that the aerobic energy system is the main source (98%) of energy provision during a soccer match (Bangsbo, 1994a). The relative $\text{VO}_{2\text{max}}$ values reported for elite adult soccer players range between 55 to 70 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; the higher values tending to be found at the top level of soccer (Bangsbo et al., 1991; Davis, Brewer, & Atkin, 1992; Raven, Gettman, Pollock, & Cooper, 1976; Reilly & Williams, 2003a; Wisloff, Castagna, Helgerud, & Hoff, 2005). In regards to $\text{VO}_{2\text{max}}$ it has been reported that soccer players maintain 75 to 77% $\text{VO}_{2\text{max}}$ for the duration of a 90 minute game (Krustrup et al., 2005; Van Gool et al., 1988). Mean HR during a soccer match range from ~156 to 167 $\text{b}\cdot\text{min}^{-1}$ (Ali & Farrally, 1991; Bangsbo, 1994b; Krustrup et al., 2005; Krustrup et al., 2006; Mohr, Krustrup, Nybo, Jung Nielson, & Bangsbo, 2004; Strøyer, Hansen, & Klausen, 2004; Thatcher & Batterham, 2004; Van Gool et al., 1988). In relative terms, a soccer player's mean HR during match play has been reported to range from 81.7 to 93.6% of HR max ($\%\text{HR}_{\text{max}}$) (Bangsbo et al., 2006; Helgerud et al., 2001; Krustrup et al., 2005; Krustrup et al., 2006; Mohr et al., 2004; Strøyer et al., 2004; Thatcher & Batterham, 2004; Van Gool et al., 1988).

2.4 SOCCER PERFORMANCE AND CREATINE

Given the physical demand of soccer, it is of particular interest as to whether athletes involved in repeated bouts of high-intensity training (i.e. soccer training) would benefit from acute short-term Cr supplementation. It seems logical that highly trained athletes who participate in sports by which performance relies on repeated high-intensity efforts could benefit from Cr ingestion through means of an increased ability to perform and recover from intermittent high-intensity exercise bouts either during training or competition. However, few studies exist which have investigated the effects of acute short-term Cr supplementation on soccer-specific performance, especially those using a soccer simulation protocol (Cox, 2002). Studies which have investigated the effects of acute short-term Cr supplementation on soccer performance (Cox, 2002; Mujika, Padilla, Ibanez, Izquierdo, & Gorostiaga, 2000; Ostojic, 2004; Smart et al., 1998) have only tested certain aspects / variables found within a soccer match (e.g. sprinting, jumping, etc) and have not fully replicated (using an appropriate soccer simulation performance protocol) most demands found in a 90 minute soccer game. Such studies are discussed below and presented in Table 3.

Ostojic (2004) examined the effects of acute short-term Cr ingestion ($30 \text{ g} \cdot \text{day}^{-1}$ for seven days) on soccer performance in younger soccer players (16.6 ± 1.9 years). Each subject underwent a series of soccer-specific tests: dribble test, sprint power test, vertical jump and a maximal multistage 20 m shuttle run test. There were significant improvements for the Cr group in sprint test times (18.6% faster Vs 3.7% slower in time for placebo group), vertical jump height (10.8% increase in height Vs 0.4% decrease for

placebo group) and soccer-specific dribble test times (21.5% decrease in time Vs 2.3% decrease for placebo group). Changes in body-mass were not reported. Shuttle run performance was not significantly affected in both groups, indicating that Cr did not impact positively or negatively on endurance performance. Similarly, Mujika et al (2000) documented sprint performance to improve and endurance performance not to improve after acute short-term Cr supplementation. Mujika et al (2000) tested 19 highly trained male soccer players. After an initial baseline control session, players were assigned to either a Cr group (ingested 20 g.day⁻¹ for six days) or a placebo group (ingested 20 g.day⁻¹ of maltodextrins for six days). Subjects completed a circuit of exercises which included three maximal counter movement jumps, followed by six maximal 15 m sprints interspersed with 30 s recovery, followed by an intermittent endurance test, and then followed by two final counter movement jumps (two minutes and five minutes into recovery). One of the main findings of the study was the improvement in five meter mean sprint times (0.02 s decrease in time; 2.1%; $p < 0.05$) in all six sprints in the Cr group compared to the times of the placebo group. There was also a slight increase in mean body-mass (0.81%; $p < 0.05$) in the Cr group with no change in the placebo group. There was also no significant differences between groups in counter movement jumps, unlike the previous study (Ostojic, 2004), who found explosive leg power (vertical jumps) to improve by ~11%. One reason Mujika et al (2000) gave as to why there was no change in the counter movement jumps after Cr ingestion was that the subjects were possibly “detrained”, as there was a “drastic reduction in training during the intervention week”. However, this does not seem very likely, as subjects improved their repeated sprint times after Cr supplementation, and if there was a detraining effect; it would have had negative consequences on other performance variables. A positive taper effect may even be expected.

In contrast to the above studies, Cox et al (2002) administered a study on 14 elite female soccer players who either ingested Cr (20 g·day⁻¹) or a placebo (20 g glucose·day⁻¹) for six days. All subjects performed a soccer-specific protocol before and after Cr supplementation. The protocol consisted of five 12 minute exercise testing blocks based on activity profiles of the subjects' previous soccer matches. Each of these five testing blocks consisted of eleven maximal 20 m running sprints, two agility runs, and one precision ball kicking drill, separated by several recovery 20 m walks, jogs and runs. The key findings of this study were the improved performance in nine of the 55 repeated 20 m sprints, and improved agility times in six agility runs of blocks two to four (2.2%) in the Cr group post-test, despite an increase in body-mass (1.3%). The Cr group achieved consistently faster post-supplementation times between sprints 10 and 47, reaching statistical significance in nine out of 55 twenty meter sprints. The mean time for the six agility runs in blocks two to four was significantly lower (11.3 ± 0.6 s pre-test and 10.96 ± 0.5 s post-test, $p = 0.02$) after Cr ingestion, and the mean time for all 55 twenty meter sprints decreased from 3.75 ± 0.19 s to 3.69 ± 0.18 s (1.6%). The change in mean time for the ten agility runs in the Cr group were 11.2 ± 0.6 s pre-test and 10.9 ± 0.4 s (2.7%) post-test, but did not reach statistical significance. Only 2 / 55 twenty meter sprints significantly decreased post-test in the placebo group, and only the second agility run of exercise testing block five was significantly lower post-test. The decreased mean sprint and agility times in the Cr group did not reach statistical significance; however, the observed mean improvement of 0.06 s across 20 m sprints and 0.3 s in the agility runs represent improvements of 1.6% and 2.7% respectively. With regards to performance, this percentage change converts to a gained distance of ~30 and ~70 cm respectively which would most likely be beneficial to the outcome in a soccer match e.g. whether or not a defender could make a last second sprint to tackle and / or block a strikers shot on goal. Smart, McKenzie et al (1998) also documented

no improvement in sprint performance after acute short-term Cr supplementation. The authors investigated the effects of six days acute Cr supplementation ($24 \text{ g}\cdot\text{day}^{-1}$) on thirty maximal 20 m running sprints, and each effort was repeated after 30 sec rest. Eleven Bruneian national league soccer players completed two testing sessions, one week apart during a break in the Malaysian Premier League. There were no significant sprint performance changes between the two testing sessions for each group. However, there was a significant increase in body-mass in the Cr group (1.9 kg) and no change was observed in the placebo group. The observed large increase in body-mass could possibly be the reason why there was no change in repeated sprint performance in the Cr group.

The aforementioned studies all used similar dosages (20 to $30 \text{ g}\cdot\text{day}^{-1}$) of Cr and similar dosage periods (6 to 7 days). Body-mass increased on average 1.4% and repeated sprint times decreased on average 7.6% in the Cr group in three of the four studies after acute short-term Cr ingestion. Interestingly, endurance performance was unchanged in all four studies. Overall, these findings suggest a potential usefulness of Cr use in soccer. However, some limitations in all four studies should be acknowledged. For example, only Mujika et al (2000) tested for urinary creatinine content to determine if the subjects Cr stores were full after supplementation. Although urinary creatinine was increased in the Cr group post-test, it was not significantly different from pre-test values. Perhaps, if the subjects Cr stores were all identified as being significantly elevated post-test in these studies, it can possibly be concluded that the dosage range and time period was sufficient enough to elevate the Cr stores in the body, as it has been documented that increased urinary creatinine content has been linked to increased Cr stores after Cr supplementation (Hultman et al., 1996). If Cr stores were shown to be full, it may have

been possible to observe a greater change in performance in the Cr groups; however, more research is needed into this area.

Most of the aforementioned studies, suggested they were investigating the effect of Cr on “soccer performance”. Although many studies have used repeated sprint performance to test for the sprinting aspect in a soccer game, most of the sprinting distances used have been too long both in distance and duration. For example, soccer players’ only sprint short distances over a few meters / seconds, yet most of the above studies have used 15 to 20 m distances only. It seems logical that when assessing soccer performance, the protocols used have to be very specific to the demands associated with soccer. We can only properly assess soccer performance by combining and simulating the demands found in a soccer game (e.g. walking five meters, then sprinting ten meters, then changing direction etc), not just testing performance measures in isolation (e.g. session one = vertical jump x 3 times, session two = sprinting 20 m thirty times).

Although the majority of studies demonstrated Cr to enhance anaerobic performance (Cox, 2002; Mujika et al., 2000; Ostojic, 2004), we cannot conclude with confidence that these effects would be observed during a full 90 minute soccer match, as these studies did not use an appropriate soccer-specific simulation protocol or utilise sprint measures over an extended time-frame. Therefore, an appropriate simulation protocol needs to be devised (that replicates most demands placed upon a soccer player in a real life soccer match), so that the true effect of Cr on “actual” soccer performance can be determined. Although soccer-specific simulation protocols have been devised, many lack the physical demands (turning, jumping, sprinting, walking, shooting etc),

distances and durations found in a game of soccer. Protocols designed to date are discussed in the following section.

Table 3: *Acute short-term creatine ingestion and soccer performance*

References	Subjects	Standard of Player	Duration	Measures	Groups	Cr Dosage	Results
Cox et al (2002)	14 F T (22.1 yrs)	National Soccer Team (Australia)	6 days	Soccer-specific test	Cr & Pla	20g/day x6 days	-↑ BM in Cr group (1.3%) -↓ in 9 sprint times in Cr group and only 2 in Pla group post-test (% unknown) -↓ in 6 (blocks 2-4) agility times in Cr group (2.2%) -N/C in accuracy shooting or RPE post-test
Ostojic, S (2004)	20 T M (16.6 yrs)	Yugoslav Junior League	7 days	Dribble test Sprint-power test VJ Endurance test	Cr & Pla	30g/day x7 days	-↓ Dribble times in Cr group (23.1%) -N/C in placebo -↓ Sprint times in Cr group (18.6%) -↑ VJ in Cr group (10.8%) -N/C in endurance performance
Mujika et al (2000)	19 T M (20.3 yrs)	Highly Trained (unknown)	7 days	Repeated sprint test CMJ Intermittent endurance test	Cr & Pla	20g/day x6 days	-↑ BM in Cr group (0.90%) -N/C in CMJ or IET -↓ Mean 5m sprints (2.1%)
Smart et al (1998)	11 T M age unknown	Premier League (Malaysia)	6 days	x 30 max sprints of 20m every 30 sec	Cr & Pla	24g/day & 30g glucose x6 days	-↑ BM in Cr group (1.9kg) -N/C in sprint performance in both groups

BM = Body-mass, N/C = No change, ↑ = Significant increase (p<0.05), ↓ Significant decrease (p<0.05), Cr = Creatine, Pla = Placebo, Wks = Weeks, T = Trained, M = Males, F = Females, Yrs = Years, CMJ = Counter movement jump

2.5 SOCCER / INTERMITTENT SPORTS PERFORMANCE TESTS

Several soccer-specific laboratory and / or intermittent team field-based exercise protocols to assess physiological and metabolic responses and patterns of intermittent exercise have been devised to date (Abt, Reaburn, Holmes, & Gear, 2003; Bishop, 2005; Cox, 2002; Drust, Reilly, & Cable, 2000; Krstrup et al., 2003; Mujika et al., 2000; Muller, 1992; Nicholas, Nuttall, & Williams, 2000; Stuart, Hopkins, Cook, & Cairns, 2005; Thatcher & Batterham, 2004). However, many of these protocols have failed to adequately simulate the physical demands and activity patterns found in an intermittent team field game, especially that of soccer performance. It is acknowledged that it is difficult for sport-specific protocols to simulate every physical demand and skill performed in a soccer match (due to the spontaneous nature). Previously designed team sport simulated protocols do lack many of these demands. However, improvements on these designs can easily be made. The soccer-specific and intermittent team sport protocols that have been devised to date are discussed below and illustrated Table 4. Two types of soccer-specific simulation protocols have been devised; 1) lab-based protocols and 2) field-based protocols.

2.5.1 Soccer simulation protocols

2.5.1.1 Lab-based soccer simulation protocols

Drust, Reilly and Cable (2000) designed a soccer-specific protocol performed on a motorised treadmill. Seven male university players were recruited for this study and each visited the laboratory on three separate occasions six days apart. The soccer-specific intermittent protocol consisted of different exercise intensities observed during soccer match-play (e.g. walking, jogging, cruising and sprinting etc). The proportions

of activities incorporated were similar to those reported by Reilly and Thomas' (1976). A recovery period was also included in the protocol, in which the subjects stood stationary on the treadmill for 71 s. The speeds chosen for all subjects for each activity were as follows: walking 6 km.h⁻¹, jogging 12 km.hr⁻¹, cruising 15 km.h⁻¹, and sprinting 21 km.h⁻¹. The total duration of the test representing one half of a soccer match was 46 min 11 s. The protocol consisted of two 22.5 minute cycles separated by a static recovery period of 71 s. Each cycle integrated 23 discrete bouts of activity: six bouts of walking, six bouts of jogging, three cruises, and eight sprints. Mean HR for the protocol was 168 ± 10 b.min⁻¹ (~83% HR_{max}). In a similar study, Abt et al (2003) designed a non-motorised treadmill test to replicate the speeds of team sport activity (especially that of soccer). Five male recreation team sport players followed an activity profile on a monitor placed at eye level which displayed a target speed together with their current speed. The players were instructed to change speed by audio bleeps and verbal commands generated by a computer over two 45 minute "halves". During the 90 minute protocol players walked 37%, jogged 24%, ran fifty percent of maximum 14%, and ran seventy percent of maximum 4%, sprinted 3% and stood stationary 18%. Players covered a mean total distance of 10196 ± 403 m. Thatcher & Batterham (2004) used six male professional English soccer players to run a soccer-specific exercise protocol (SSEP). The SSEP consisted of two bouts of 9 x 5 min repeated cycles on a non-motorised treadmill, separated by a 15 min rest period (half-time). All subjects were given a visual cue via a computer that displayed both the target speed and treadmill speed. The distance of the SSEP (9924 m) was similar to that observed during an English premier soccer match (9741 ± 882 m to 10274 ± 609 m). Mean HR responses in the SSEP were; first half: 166 ± 13 b.min⁻¹ and second half: 166 ± 11 b.min⁻¹. One clear advantage that Abt et al (2003) and Thatcher et al's (2004) protocol had over the protocol designed by Drust et al (2000) was that they were both performed

on a non-motorised treadmill, not on a motorised treadmill. Subjects using a non-motorised treadmill can change speeds at their own pace, which can make it easier for researchers, coaches and trainers to observe a fatiguing effect within the subjects over the course of the protocol. The target speeds can also be reached a lot quicker when using a non-motorised treadmill, as there is sometimes a long time delay when changing speeds on a motorised treadmill. Another advantage that these two studies had over Drust et al (2000) was that the total distance covered during the protocols were both similar to the distances covered during a soccer match (Bangsbo & Lindquist, 1992; Bangsbo et al., 1991; Helgerud et al., 2001; Krstrup et al., 2005; Mohr et al., 2003; Rienzi et al., 2000; Thatcher & Batterham, 2004; Van Gool et al., 1988; Withers et al., 1982). However, it should be acknowledged that Drust et al (2000) did highlight their protocol was designed to represent one half of a soccer match (~45 min). It is unknown if Abt et al's (2003) treadmill protocol had similar mean HR values to those found in a soccer game as they were not reported. Drust et al (2000) and Thatcher et al's (2004) protocols both had similar mean HR values to those previously found in soccer matches (Ali & Farrally, 1991; Bangsbo, 1994b; Krstrup et al., 2005; Krstrup et al., 2006; Mohr et al., 2004; Strøyer et al., 2004; Thatcher & Batterham, 2004; Van Gool et al., 1988).

One positive aspect of lab-based soccer-specific protocols is that they can replicate the speeds and distances found during a soccer match. Consequently the physiological load is specific to a soccer game. Standardisation of the lab environment (consistent air temperature, humidity, barometric pressure etc) is another positive aspect of lab-based interventions. A clear limitation of all three lab-based protocols is that no reliability studies or validity studies have been undertaken on them; therefore we cannot determine

the amount of error present in each protocol. However, one study by Hughes, Doherty, Tong, Reilly & Cable (2006) examined the reliability of repeated sprint exercise in non-motorised treadmill ergometry and found maximal speed was highly reliable (CV = 2.75%). Due to these tests being performed on treadmills, subjects were restricted to straight line running only; therefore no agility / change of direction movements or ball-skills were performed throughout the test, which are major characteristics of team sports, especially that of soccer, and these are likely to change the demands of the task and the effect on muscle fatigue.

2.5.1.2 Field-based soccer simulation protocols

The second type of soccer-specific simulation protocol designed is the field-based protocol. Bangsbo and Lindquist (1992) designed a soccer-specific performance protocol (refer Appendix 4a) that consisted of forward, backwards and sideways running, and weaving in and out of slalom flags. The test lasted 16.5 minutes, during which players alternated between 40 bouts of high-intensity exercise each lasting fifteen seconds, and 40 bouts of low-intensity exercise each lasting ten seconds. During the high-intensity periods, subjects followed an outlined circuit around a penalty area of a soccer field. Players ran 40 m forward, 8.25 m backwards, 95.25 m forward and then through a 120 degree angled slalom, 8.25 m sideways while facing away from the centre of the circuit, and 8.25 m sideways while facing the centre of the circuit. During the low-intensity periods, players jogged to the centre of the circuit and back to the last cone marked position they reached at the end of the previous high-intensity period. Despite the soccer-specific movements involved in this study (high and low-intensity running, backwards movements, agility etc), there were still no integrated ball-skill activities (such as shooting, passing etc), or any reported replication of soccer match

distance or duration. Muller, Kornex & Leitenstorfer (1992) designed a similar soccer-specific endurance protocol to that of Bangsbo and Lindquist (1992), which was based off a previous design by Binz (1986). The protocol had a total distance of 205 m and took approximately 76 s per lap, for a total duration of 10.08 minutes. The protocol included jogging; sprinting, walking, jumping hurdles (80 cm), and backwards running. There was also sprinting with soccer balls and shooting accuracy integrated which made the protocol more soccer-specific; however no agility movements (i.e. slalom movements) or jumping movements were performed (unlike Bangsbo and Lindquist's protocol). Muller et al (1992) did well to replicate many of the movement patterns and skills found in a soccer game, as every movement pattern performed had a time limit. For example, subjects had to walk 20 m in 13 s; jog 40 m in 12 s; and sprint 13 m in 2 s, etc. This idea was supposed to control the pace of the subjects, however the authors did note there was a limitation of this, stating "the planned running intensity and time were not exactly maintained during the test", possibly due to motivation levels and / or fatigue. Another similarity of this protocol to Bangsbo and Lindquist's (1992) was the minimal distance covered (205 m) and time taken to complete (~10 minutes). One advantage that Muller et al's (1992) protocol had over Bangsbo and Lindquist's (1992), was that it was described by the authors as being highly reliable (product-moment correlation coefficient $r = 0.90$), whereas Bangsbo and Lindquist (1992) did not illustrate any reliability results or studies undertaken on their field test.

In regards to longer duration (>75 minutes) soccer-specific field protocols, only two to date have been devised (Cox, 2002; Nicholas et al., 2000). Firstly, Nicholas et al (2000) devised the Loughborough Intermittent Shuttle Test (LIST) to simulate the activity patterns common to soccer performance, without any contact (refer Appendix 4b).

Seven trained healthy male soccer and rugby players were used as subjects. This protocol consisted of two parts, A and B. Part A was of fixed duration and consisted of five 15 minute exercise periods separated by three minutes of recovery. Part A consisted of bouts of walking, and running at speeds corresponding to 55 and 95% of an individual's pre-determined $\text{VO}_{2\text{max}}$ over a 20 m distance. Part A was as follows: 3 x 20 m at walking pace, 1 x 20 m at maximal running speed, 4 s recovery, and 3 x 20 m at running speed corresponding to 55% of individual $\text{VO}_{2\text{max}}$, 3 x 20 m at a running speed corresponding to 95% of individual $\text{VO}_{2\text{max}}$. Part B was an open-ended period of intermittent shuttle running, designed to exhaust the participants within ten minutes. The duration of the LIST was approximately 75 minutes and the total distance covered was 12400 m. The mean HR for trial one and trial two for part A was 169 and 171 bmin^{-1} and part B was 175 and 176 b.min^{-1} . The distance and mean HR values were similar to those calculated in professional soccer matches (Bangsbo et al., 1991; Reilly & Thomas, 1976; Van Gool et al., 1988). The duration of the LIST was 15 minutes shorter than a soccer match. Cox et al (2002) used 14 elite female soccer players from the Australian National Soccer Team. Subjects participated in two performance testing sessions separated by seven days. This soccer protocol consisted of five 12 minute exercise testing blocks (11 minutes of exercise and one minute of recovery) based on activity patterns previously observed in female soccer players. Each of these testing blocks included eleven all-out twenty meter sprints, two agility runs, and one precision ball kicking drill, separated by several standardised recovery twenty meter walks, jogs and runs. The test lasted approximately 60 minutes which was also less than a soccer match (~30 min) and 15 min shorter than the LIST. The mean HR of 174 b.min^{-1} was also similar to that observed in a soccer match (Bangsbo et al., 1991; Reilly & Thomas, 1976; Van Gool et al., 1988) and similar to the mean HR documented in the LIST. The distance covered during Cox's (2000) protocol was not reported. One advantage of

Cox's (2000) soccer-specific protocol had over the LIST was Cox included ball-skills, whereas the LIST had no ball-skill work. Cox (2000) did not report whether a reliability study had been performed on his protocol, whereas the authors of the LIST did note reliability was within the "observed limits".

2.5.2 Other team sport protocols

Other team sports such as rugby and field hockey both have similar performance demands to those found in a soccer game. Agility, short repetitive sprints, and aerobic endurance are all key aspects to rugby, field hockey and soccer. Rugby and field hockey simulation protocols will be discussed below. It is useful to consider other protocols from other sports, as ideas can be implemented into future soccer protocols.

Stuart et al., (2005) designed a protocol based on time-motion analysis of first-class level rugby union games. Eleven Auckland premier team players aged 25 ± 4 years took part in the study. The test consisted of 14 circuits, each circuit made up of 11 stations for activities that included sprinting (straight line and agility), peak power in two consecutive drives, passing accuracy and rest periods of standing or walking. The 14 circuits were split into two 40 minute halves with a 10 minute half-time break in between to replicate a rugby match. The total distance covered, and HR values were not reported in this study. This rugby performance protocol closely simulated activities performed in rugby (sprinting, ball passing, tackling etc) and was of real match duration (40 minute halves with a 10 minute half-time rest to simulate the game of rugby). A similar approach to identify the effect of Cr on soccer performance is clearly needed.

Bishop and Claudius (2005) designed an intermittent sprint protocol based on the motion analysis of international field hockey and was also designed to simulate the average sprint profile of a typical team-sport game, and consisted of two 36 minute halves of intermittent activity on a cycle ergometer. The protocol was divided into ~2 minute blocks of sprinting, active recovery, and passive rest. Each block began with an all-out four second sprint, immediately followed by 100 s of active recovery. One limitation is that the testing was performed on a cycle ergometer. As this protocol was designed to test an athletes (in this case hockey) sporting performance, the test should have replicated / included the running characteristic of a hockey match (for example, the test should have used a non-motorised treadmill instead of a cycle ergometer) to make it more sport-specific. Other limitations of the protocol include the lack of agility / direction change and passing / shooting accuracy, which are all very important characteristics of field hockey and other team sports. Bishop and Claudius (2005) however, did do well to replicate the duration of a field hockey match (~35 minutes each half) in their intermittent sprint protocol. It also has to be noted that no reliability study has been undertaken using this protocol. The total distance covered was also not reported in this study. In another field hockey study, Sunderland et al., (2006) investigated the reliability and validity of a field hockey skill test using 39 male and female hockey players. The protocol was designed to use elements of a hockey game including shooting, passing and dribbling and was performed on a water-based sports turf (the type of surface all the subjects regularly play and train on). The mean time to complete the field test was 90.85 ± 9.21 minutes. It is well known that the typical game duration of field hockey is approximately 70 minutes (~35 minutes each half), therefore we can conclude that this hockey simulation protocol was too long in duration (~20 minutes) to replicate a game of hockey. The authors noted the protocol as having “good reproducibility” (typical error = 1.9 s, Pearson correlation coefficient $r = 0.96$, ICC =

0.96, mean difference with CI = 0.0 s, -0.9, 1.0). We can use and modify this hockey simulation protocol by integrating different stations into them relevant to soccer performance (for example, a goal shooting or ball passing exercise instead of a hockey shooting station etc).

Table 4: *Soccer and intermittent team sports performance protocols*

Author(s)	Subjects	Name of protocol	Duration	Reliability (Y/N)	Pros	Limitations
Abt et al (2003)	5 M recreation team sport players (20 yrs)	Non-motorised treadmill protocol	90 minutes	N	-Replicates the speeds, duration, distance and rest intervals performed in team sports	-No change of direction/agility -No ball-skills
Bangsbo & Lindquist (1992)	14 M soccer players (17.5 yrs)	The Bangsbo Field Test	16.5 minutes	N	-Sideways, forward & backward motion -Simple to run/set up -Performed on a soccer pitch -Replicates high and low intensity running	-Short duration (16.5mins) ∴ Poor replication of distance -No replication of balls skills, passing, shooting etc
Bishop & Claudius (2005)	7 F team-sport athletes (19 yrs)	Intermittent Sprint Test	Two 36 minute halves	N	-Replicates the speeds, duration and rest intervals performed in team sports	-Performed on a cycle ergometer -No change of direction or agility -No shooting/passing accuracy
Cox (2002)	12 elite F soccer players (22.1 yrs)	No name	60 minutes (5 x12 min ex blocks)	N	-Integrated agility run -Integrated precision ball kicking -Performed in an indoor soccer are	-Moderate duration (60 mins)
Drust, Reilly & Cable (2000)	7 M soccer players (24 yrs)	Soccer-specific Treadmill Test	46.11 minutes	N	-Good replication of running speeds and average HR	-No agility, side or backwards running -Performed on a treadmill -Short duration -No replication of balls skills, passing, shooting etc

Muller et al (1992)	40 M soccer players (age unknown)	Soccer-specific endurance test	10.08 minutes (8 laps/76sec per lap)	Y	-Replicates the speeds, rest intervals, and ball-skills performed in a soccer match	-Planned running time or intensity is not exactly maintained -Maximal frequency was not reached in the sprints -Short duration
Nicholas et al (2000)	7 T M soccer and rugby players (21.5 yrs)	Loughborough Intermittent Shuttle Test	75 minutes (Part A & B)	Y	-Replicates the distance covered (12.4 km) and mean HR in a soccer match	-No replication of balls skills
Stuart et al (2005)	11 T M premier rugby players (25 yrs)	Rugby Test	80 minutes	N	-Replicates the duration, ball- skill & movements of a rugby match	
Sunderland et al (2006)	14 T M & 17 T F hockey players (age unknown)	Field Hockey Skill Test	90 minutes	Y	-Replicates the duration, skill and movements of a hockey match	
Thatcher et al (2004)	6 T M soccer players (19.3 yrs)	Soccer-specific exercise protocol (SSEP)	x 2 bouts of 9 x 5 minute cycles on non- motorised treadmill	N	-Replicates the speeds, duration, distance, HRs and %VO _{2max} of a soccer match	-No agility or ball-skills

Although there have been many team sport simulation protocols designed, there are none that have included and completely replicated the intensity (HR, VO_2), duration, distance, ball-skills work, movement patterns and general soccer skills that are required / observed in a soccer match. Most studies have replicated only a few of these qualities in their protocols. Despite the apparent positive effects of Cr supplementation in team sports athletes using different repeated sprint tests, a common limitation of the aforementioned studies is that a sport-specific performance measure (i.e. 90 minutes of soccer-specific intermittent exercise) was not used. Therefore, it is unknown whether such physiological gains are transferred to the actual game of soccer (i.e. over the whole 90 minute period).

Having a soccer-specific protocol that can simulate the duration and demands of a soccer game can benefit the athlete, trainer and coach as it illustrates where exactly in a game (first 30 minutes or last 15 minutes), and what / where the athlete's weaknesses are (jumping ability, shooting etc), without the athlete having to play and be analysed during an actual competitive soccer game. If a soccer performance protocol is inadequate in duration and does not replicate an entire soccer game, it makes it very difficult to determine whether there are any effects from a training or nutritional intervention on an athletes entire 90 minute performance. Clearly, a closely controlled, sport-specific soccer simulation protocol that reflects the most recent temporal analysis of soccer match-play (e.g. number of sprints, turns, game distance, duration / distance of sprints, recovery duration, HR, game duration etc) will help to accurately determine the potential performance enhancing effects of Cr supplementation.

2.5.3 Conclusion

In summary, Cr supplementation could potentially improve intermittent sport performance and in-turn soccer performance by 1) increasing the number and intensity of high-velocity sprints (Cox et al., 2002; Kreider et al., 1998), and 2) promoting quick ATP-PCr resynthesis (Greenhaff et al., 1994) therefore allowing athletes to compete and train at a higher intensity (Kreider et al., 1998; Vandenburghe et al., 1997). To date, only a handful of studies have devised a soccer simulation protocol, and those that have are limited in their ability to closely replicate the demands of soccer match-play. Other intermittent sport protocols have also been devised (rugby and field hockey) and have done well to simulate the match-play of their sport. Although these protocols do have limitations, many can be modified and re-designed for soccer performance. As no study to date that has investigated the effects of acute short-term Cr ingestion on soccer performance using an appropriate 90 minute team sport simulation protocol (especially that of soccer), the aim of this study is two-fold; 1) to design and determine the validity and reproducibility of a soccer simulation protocol; and 2) determine the effects of acute (1 week) short-term Cr ingestion on soccer-specific performance (using the BEAST).

CHAPTER THREE: Methods

3.1 Experimental Design

Two experimental designs were adopted for this thesis. For study one, a test-retest design was used to determine the reliability and validity of the Ball-sports Endurance And Sprint Test (BEAST). For study two, a randomised, triple-blind, placebo-controlled experimental design was adopted to determine the efficacy of acute short-term Cr supplementation on soccer-specific performance, using the BEAST. This project was evaluated and approved by the Auckland University of Technology, Human Subject Ethics Committee.

3.2 Subjects

Twenty healthy male first, second and third division soccer players from a local soccer league volunteered to participate in the study. Subjects were pre-screened via medical questionnaire for any previous or current injuries and medical conditions that would contraindicate participation. In addition, subjects were required to attest to having not consumed any sporting ergogenic aid(s) over the three month period prior to the study. Each subject provided written informed consent (refer Appendix 2) before any testing commenced. However, due to injuries, sickness and other personal commitments, only 15 players completed both studies. This sample was comprised of six defenders, five midfielders, three strikers and one goalkeeper. The descriptive characteristics of subjects are presented in Table 5.

Table 5: *Participant descriptive characteristics. Values are mean \pm SD*

Group	Age (years)	Height (cm)	Body-mass (kg)	Playing Experience (years)
Creatine (N=7)	25.4 \pm 4.5	179.3 \pm 4.6	79.3 \pm 10.5	18.7 \pm 5.4
Placebo (N=8)	26.7 \pm 4.6	178.9 \pm 5.1	80.8 \pm 8.6	19.4 \pm 4.3

3.3 Test Protocols

The BEAST was conducted indoors in a well-ventilated sports stadium at Auckland University of Technology. All subjects were required to attend five testing sessions (refer Figure 1). The BEAST protocol was designed from previous match analysis studies (Bangsbo et al., 1991; Mayhew & Wenger, 1985; Reilly & Thomas, 1976; Withers et al., 1982). The Yo-Yo / $\text{VO}_{2\text{max}}$ testing sessions were also undertaken in the same ventilated sports stadium as the BEAST. Running economy was measured indoors in a well ventilated laboratory at Auckland University of Technology.

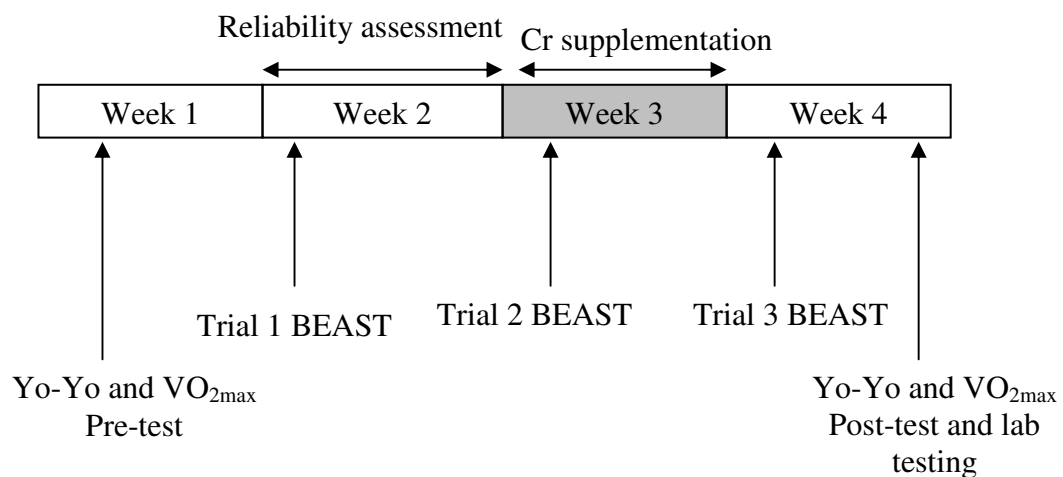


Figure 1: *Schematic illustrating the combined study design and time line*

3.3.1 The Ball-sports Endurance and Sprint Test (BEAST) protocol

The BEAST (refer Figures 2 and 3) is a soccer-specific protocol designed to simulate the physical demands of a typical competitive soccer game (i.e. it is run continuously over a 90 minute period consisting of two 45 minute halves, with a half-time break of ten minutes). The 90 minute BEAST was modified from an 11 minute protocol previously designed by Abt (2006). A shooting station and vertical jump station were added to the original version. Only a single subject can run the BEAST at any given time.

The BEAST protocol consisted of two laps, which made up one circuit (refer Figures 2 and 3). Each circuit was repeated continuously for the duration of the half (45 minutes), followed by a half-time recovery (ten minutes); then repeated for a further 45 minutes (second half). One circuit has a distance of 380.4 m. Sprinting, backwards jogging, walking, jogging / decelerating, and forwards running (75% of at maximum effort), make up 8.4%, 8.4%, 9.7%, 24.5% and 39% of the total distance covered per circuit.

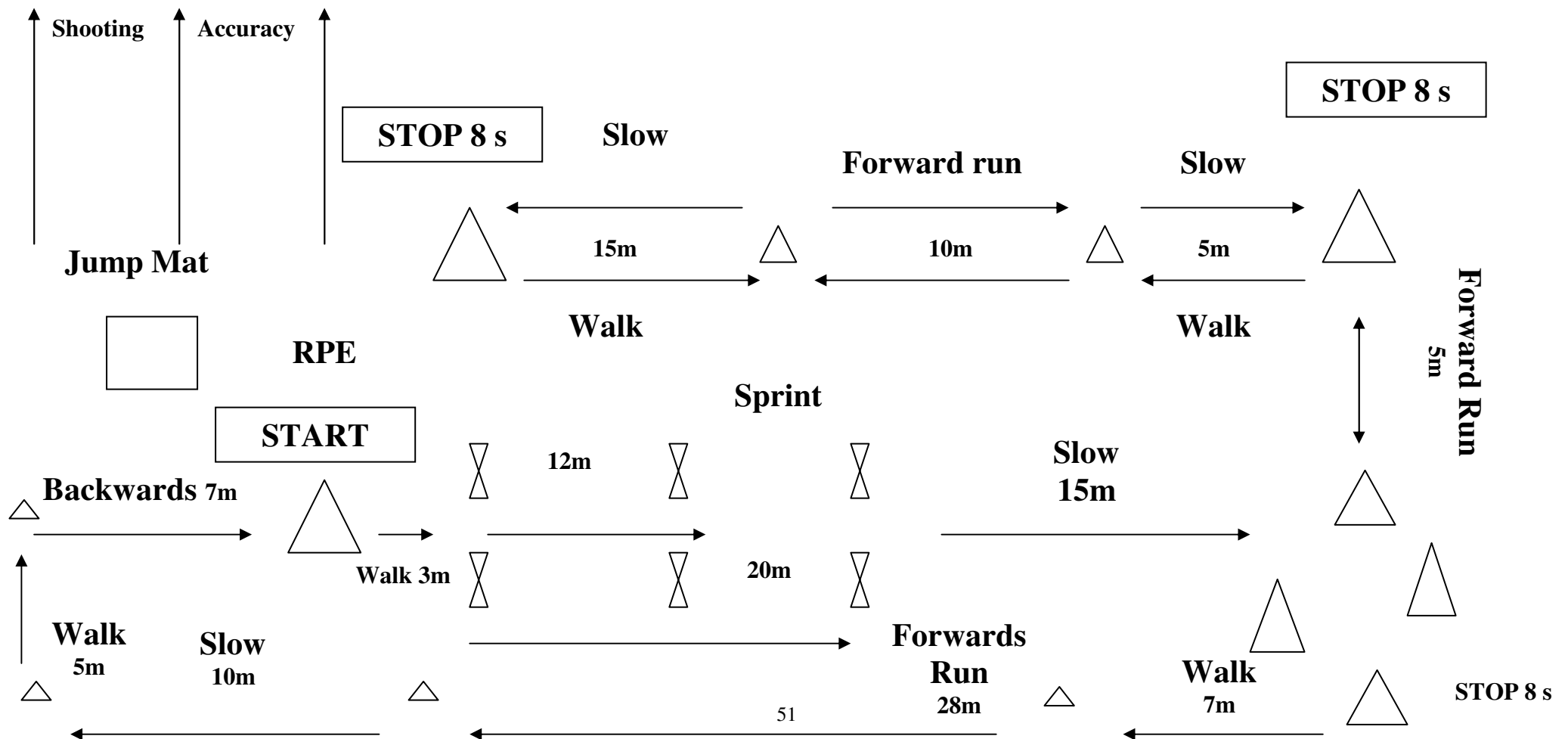


Figure 2: *Ball-sports Endurance And Sprint Test (BEAST)*

Figure 3: Schematic design of the BEAST protocol

Ball-Sports Endurance And Sprint Test (BEAST)

Accuracy Goal



3.3.1.1 Circuit Description

The first lap (of two) was completed as follows (refer Appendix 5a):

The subject stood stationary at the start cone and when the signal was given by the circuit timer, the subject walked forward at a brisk pace for three meters. The subject then stopped at the sprint start line placed 50 cm behind the first pair of photocells. Visible signs (i.e. sprint 12 m, run 5 m, walk 5 m etc) were placed at every station to remind the subject what movements they were to perform. On the researchers' signal (~2 s) the subject sprinted maximally through the 12 m photocells (the subject was instructed to sprint one meter past the 12 m gates to reduce a slow-down effect). The subject then decelerated in a straight line for 23 m to the next cone. He turned left at the cone and ran forwards five meters at 75% of maximum pace to the next cone. The circuit timer then instructed the subject to stop at this cone for a period of eight seconds (giving a verbal countdown of when to walk five meters to the following cone). After the five meter walk the subject ran in a straight line ten meters at (75% of his maximum pace) to the next cone, decelerated 15 m and then stopped again for another eight seconds. On the circuit timer's signal, the subject briskly walked back the way he had come (15 m). He then ran ten meters (75% of his maximum pace) and decelerated five meters until he reached the next cone, where he rested again for another eight seconds. He then ran five meters at (75% of his maximum pace) and weaved in and out of the slalom cones for a distance of approximately 6.4 m, where he stopped briefly to rest for another eight seconds. The subject briskly walked to the next cone in a straight line (seven meters) then ran (75% of his maximum pace) for 28 m and decelerated for 10 m until he reached the next cone. He then briskly walked five meters to the next cone,

then back-pedalled (backwards jog) seven meters to the start / finish line. This was one lap (half a circuit).

The second lap (refer Appendix 5b) was identical to the first except this time the subject sprinted 20 m (not 12 m) after the initial three meter walk. At the end of the second lap, the circuit time was recorded and the subject was fed six individually rolled soccer balls (the ramp was four meters away from the shooting zone, 1.5 m long, and placed on an 80 cm high bench) onto his dominant foot (e.g. left foot is fed balls from the right side and visa versa) and had to shoot at a soccer goal (indoor soccer goal measured 4.5 m long x 3.0 m high). Points were scored by shooting at either side of a centre target (inside each goal-post there were two leather straps 20 cm wide, dangling down the cross-bar 90 cm inward from the side post to replicate a goal keeper). After each ball was rolled, the subject briskly jogged from the start line to the shooting line (four meters), took his shot and back-pedalled to the start line ready for his next shot. The ball was rolled as soon as the subject back-pedalled and touched the start line with his foot. After the shooting station, the subject walked briskly to the jump mat and performed one vertical jump. The subject then verbally called out or pointed to a number on the rate of perceived exertion scale (RPE) shown to him by a research assistant.

The subject continued to complete the circuits until 45 minutes had elapsed, upon which time the subject had a ten minute half-time break.

3.4 Equipment

3.4.1 Height and Body-mass

A portable stadiometer and digital scales (Model 770, Seca, Germany) were used to measure height (cm) and clothed but shoeless body-mass (kg) respectively. Height was measured and recorded to the nearest 1 cm, while body-mass was measured and recorded to the nearest 0.1 kg during the pre-trial, half-time and full-time of the BEAST.

3.4.2 Pulmonary Gas Exchange

A portable gas analyser (Metamax 3B, Cortex, Leipzig, Germany) was used to measure and record VO_2 during the pre and post Yo-Yo intermittent level 1 test. Intra-class reliability coefficients for the portable Metamax I have previously been documented as being ‘very high’ (Meyer, Georg, Becker, & Kindermann, (2001). Before each test, the gas analyser was calibrated using certified calibration gases, and the volume turbine sensor was calibrated using a 3-L syringe (Hans Rudolf Inc., Kansas City, MO). A temperature / barometric pressure gauge (name and make unknown) was used to record temperature, barometric pressure and humidity of the sports stadium prior to every testing session. Temperature ranged from 17 to 20 degrees Celsius and humidity ranged from 55 to 70%.

3.4.3 Urine Analysis

Urine was collected 15 minutes prior to the start of each BEAST testing session (x 3 samples per athlete) using specific urine collection containers from AUT (Auckland University of Technology). Since previous work has found that once Cr stores are filled after Cr supplementation, un-wanted Cr is excreted into the urine (Greenhaff, 1997).

This technique was used to ensure Cr was indeed consumed by the experimental group. Analysis of each player's urine for Cr using a modified "Creatinine Kit" was intended, as it was successfully used by (Rawson, 2004). Due to funding restrictions, these samples were unable to be analysed. However, we are confident that muscle [Cr] in the experimental group was significantly increased after acute short-term Cr supplementation.

3.4.4 Timing Instruments

Dual electronic timing lights (Speed-Light, Swift Performance, Melbourne, Australia) were used to record 12 m and 20 m sprints during the entire BEAST protocol. In addition, a hand-held electronic timer (CDN, China) was used to ensure that the correct rest periods were employed at the 45 minute half-time break during the BEAST protocol. The electronic timer gave an audio signal when the rest time was completed, cueing the subject to begin the second 45 minute period. The investigator also gave subjects a fifteen second count down to ensure that they were properly prepared to begin at the audio cue. A stop watch (name and make unknown) was also used to time each subjects mean circuit time of the BEAST.

3.4.5 Leg power

A Swift Performance (Melbourne, Australia) Jump Mat and hand piece was used to measure explosive leg power during each circuit of the BEAST.

3.4.6 Heart rate (HR)

A Polar Team (Polar Electro, Oy, Kempele, Finland) HR monitor system was used to record maximal and mean HR (every ten seconds) during all testing sessions. A Polar

s810 (Polar Electro, Oy, Kempele, Finland) HR monitor was also used in conjunction with the Team Polar system (used as a backup).

3.5 STUDY ONE: The Reliability and Validity of the BEAST

A reliability and validity assessment of the BEAST protocol was performed prior to the main Cr supplementation experimental study.

During the first visit, each player undertook a Yo-Yo level 1 intermittent endurance test. This test has been shown to be a reliable and valid test for assessing soccer fitness (Krustrup et al., 2003). The Yo-Yo test consisted of incremental shuttle running until exhaustion. Every second 20 m length, subjects had ten seconds of active recovery consisting of 2 x 2.5 m walking light jogging. Running speed was prescribed by “beeps” occurring at timed intervals by an audio cue. Players had to reach the 20 m line by the time each “bleep” was heard. The test was terminated when the subject failed to reach the line over two consecutive times (objective evaluation by two research assistants) or he felt unable to cover another shuttle at the dictated speed (subjective evaluation). The end result was the total distance (meters) covered. Prior to the test, as a warm up, each subject ran the first seven interval stages of the Yo-Yo protocol, rested and then performed their own stretches for five minutes. During this, and subsequent Yo-Yo tests, VO_2 was measured breath-by-breath using a portable gas analyser (Metamax 3B, Cortex, Leipzig, Germany) which communicated data in real-time, via telemetry, to a nearby desk-top computer. Heart rate was also recorded (every 10 s) using a Polar s810 (Polar, Electro, Finland) HR monitor.

Approximately five to seven days later, each subject completed the BEAST protocol. Instruction on performance of the protocol was provided, accompanied by a hands-on detailed run-through with the researcher for 30 minutes prior to running the BEAST. Subjects first performed a standardised warm-up by running one circuit of the BEAST

protocol at varying intensities (50% x 1 lap and 75% x 1 lap). Subjects then commenced the actual soccer simulation protocol for 45 minutes, had a ten minute (half-time) break, and then performed the protocol for another 45 minutes. During the ten minute rest period, the subject's clothed but shoeless body-mass was recorded to the nearest 0.1 kg using electronic scales (Model 770, Seca, Germany). Subjects were permitted to drink water *ad-libitum* during the half-time break, as they would in a real soccer match. The volume of water consumed during the half was recorded and, for consistency, the same amount was provided at the half-time interval during subsequent test sessions. Subjects were then re-tested approximately five to seven days after their first initial BEAST test (refer Figure 4). All measures detailed in the previous section were determined during the 90 minute protocol (i.e. 12 m sprint time, 20 m sprint time, mean circuit time, vertical jump height, heart rate and body-mass).

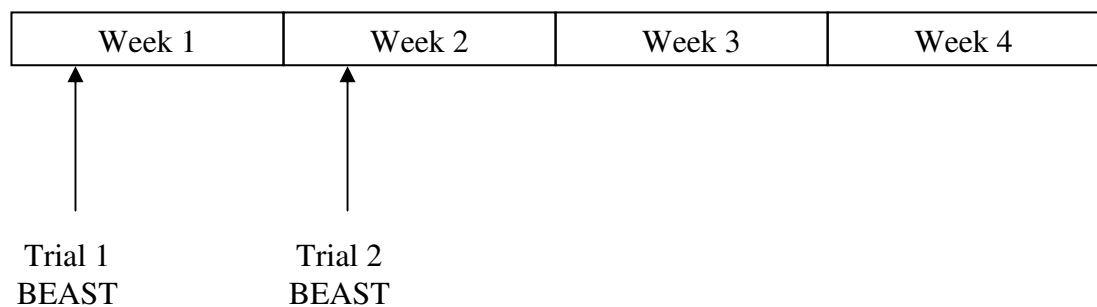


Figure 4: Schematic illustrating study one (reliability) design and time line

3.5.1 Determination of the VO_2 -HR relationship and VO_{2max}

As a warm-up for the second Yo-Yo test during week four, and to determine the VO_2 -HR relationships (for subsequent estimation of the oxygen cost of the BEAST) post-test, subjects were required to run on a motorised treadmill (Power-Jog, Birmingham, UK) at three different sub-maximal running speeds. Subjects ran at 8, 10 and 12 km.h⁻¹, each for three minutes. During each three minute stage, pulmonary gas-exchange was measured continuously using a portable breath-by-breath gas-analyser (Metamax 3b, Cortex, Leipzig, Germany). Breath-by-breath data were averaged on a 30 s basis and the VO_2 values obtained in the last 30 s of each stage were recorded for subsequent analysis. After the three stages, subjects actively rested (standing up, stretching and walking downstairs from the laboratory to the sport stadium) for approximately five minutes before performing the Yo-Yo (level 1) intermittent endurance test (with the gas analyser still attached via telemetry).

A linear regression and the percent VO_{2max} of the BEAST was calculated as follows. Subjects' mean HR and VO_2 scores were calculated at each of the three running intervals during the running economy treadmill test. These figures were then graphed, and a linear trendline equation was used to calculate each subjects VO_2 -HR relationship. Each subject's HR from the BEAST protocol were used / extrapolated in the regression equation, giving each subject an individual VO_2 figure at the different stages of the BEAST (first half, second half, whole 90 minutes). These figures were then averaged for the full squad and a percent VO_{2max} value was calculated using the average maximal HR and VO_{2max} figures calculated from the pre-test Yo-Yo scores.

3.6 STUDY TWO: The effects of acute Cr supplementation on soccer performance

Using a matched-pairs design based on their Yo-Yo intermittent test scores, subjects were assigned to either 1) an experimental group (Cr) who subsequently ingested Cr (see below) for seven days or 2) a placebo group (placebo) who subsequently ingested corn-flour mixed with glucose for seven days. Each subject's diet was recorded two days prior to the test session and subjects were advised to keep their diet similar for the following week. After seven days supplementation (i.e. on day eight), each subject repeated the BEAST (Trial 3 or post-test) protocol. Approximately, two to seven days after completing their final BEAST trial, the subjects performed their post-test $\text{VO}_{2\text{max}}$ / Yo-Yo testing session.

3.6.1 Supplementation administration

Subjects were supplemented with Cr powder or a placebo for seven days following the initial pre-testing (Trial 2 or pre-test). Subjects were required to ingest their supplement four times per day with approximately four hours between dosages. Subjects who were randomised into the Cr group received seven plastic Glad Zip-Loc bags each filled with 20 grams of commercially available Cr monohydrate (Horleys, Auckland, New Zealand), which was mixed in with eight grams of glucose powder to disguise the taste. The placebo group received seven plastic Glad Zip-Loc bags each filled with 20 grams of corn-flour, mixed in with eight grams of glucose powder making it indistinguishable from Cr in terms of flavour, texture and appearance. One bag was consumed per day. Subjects were required to return the empty bags to ensure compliance. Compliance was 100%.

3.7 Statistical Analysis

Data were analysed using the statistical analysis software program SPSS for Windows (Version 14.0) and two spreadsheets devised by Hopkins (2002b); one for the analysis of reliability and the other for determination of confidence limits and clinical significance.

For study one, test-retest reliabilities of the BEAST performance measures were quantified using the standard error of measurement (SEM) (or typical error) (Hopkins, 2000), coefficient of variation (CV), and Intraclass Correlation Coefficient (ICC). There exists a variety of models and associated formulae for the computation of the ICC, but that computed by Hopkins' spreadsheet uses the 2-way mixed model (formula 3,1) described by Shrout and Fleiss (1979), and measures score consistency rather than absolute agreement. Examination of plots of change scores at Trial 2 against Trial 1 values did not indicate heteroscedasticity to be a problem and therefore no data transformations were undertaken.

A Spearman's correlation coefficient was used to determine the relationship between the total distance of the BEAST, VO_{2max} and Yo-Yo distance.

Data for study two comprised pre (Trial 2) and post (Trial 3) supplementation measures assessed during performance of the BEAST and pre and post VO_{2max} data collected during weeks one and four. Comparability of the two treatment groups prior to supplementation was assessed by independent samples t-tests (equal variances not assumed) and plots of post-test (Trial 3) change scores against the pre-test (Trial 2) values were examined to ensure a similar magnitude of change across the range of pre-

test values. The effects of Cr supplementation were analysed by repeated measures ANOVA. Most models included Group (Cr and placebo) as a between-subjects factor, Trial (pre and post) as a within-subjects factor and Interval (generally either two x 45 minutes or six x 15 minutes) as a second within-subjects factor. Bonferroni procedures were employed for post-hoc comparisons to reduce the probability of Type I errors. The ANOVA effects of primary interest were the Group*Trial and Group*Trial*Interval interactions. The former interaction assessed whether the Trial effect differed for the two groups while the Group*Trial*Interval assessed whether the Trial*Interval interaction (i.e. the differing effects of Interval with Trial) differed for the two groups. The main effect of Interval was also of interest as it assessed changes in performance during the 90 minute BEAST ignoring Trial and Group effects.

Cohen's d statistic was employed as the measure of effect size (ES) and was calculated by dividing the difference between group means by the pooled between-subject standard deviation of the group baseline scores (Hopkins, 2002a). Cohen (1988) defined a small effect as 0.20, a medium effect as 0.50 and a large effect as 0.80. ES values are reported as positive if the effect represents improvement (e.g. reduction in sprint time) and negative if the effect represents deterioration (e.g. decreased vertical jump height). ES values for the effect of Cr (relative to placebo) on performance measures over the full 90 minute BEAST protocol were determined from the Group*Trial estimated marginal means of the repeated measures ANOVAs. The pre-test mean was subtracted from the post-test mean for each group, and the resulting mean difference for the placebo group was then subtracted from the corresponding value of the Cr group. An equal variance independent samples t-test on post-pre change scores for the two groups would yield the same mean difference and also the same p-value as obtained from the ANOVA Group*Trial interaction. The ES was then calculated and entered with the

associated p-value into Hopkins' spreadsheet for determination of the ES confidence limits and the chances that the true effect was substantial (i.e. $ES \geq 0.2$). Hopkins (2002d) advocates use of the unequal variances t-test when testing for group differences on post-pre change scores since subjects in the treatment group may respond differently. Therefore, alternative analyses using an unequal variance t-test for group differences in mean change scores were also undertaken and the associated p-values entered into the spreadsheets.

Effect sizes of Cr (relative to placebo) on performance measures over the second half (45 min) of the BEAST protocol were similarly examined. These effects were pertinent to the issue of whether Cr reduced fatigue. The ES values were determined by conducting equal variance t-tests for group differences in change scores. The change scores were formed by subtracting the difference scores between the two 45 minute halves of the pre-test (i.e. Half 2 – Half 1) from the difference scores between the two halves of the post-test (Half 2 – Half 1). The equal variance t-test for group differences on these change scores is equivalent to the Group*Trial*Interval interaction test of a 2 (Group) x 2 (Trial) x 2 (Interval) repeated measures ANOVA.

Data was considered statistically significant when the probability of Type 1 error was 0.05 or less.

CHAPTER FOUR: Results

4.1 STUDY ONE: Reliability and Validity of the BEAST

Two subjects dropped out of the study after completing the first Yo-Yo and $\text{VO}_{2\text{max}}$ test due to personal commitments and injury. Also, three subjects dropped out of the study after completing Trial 1 of the BEAST (i.e. the first of the two reliability assessment trials) due to sickness and injuries.

4.1.1 Reliability

Table 6 presents the change in mean, typical error, percent typical error and intra-class correlation (ICC) results for the first half, second half and full-time of trials one and two of the BEAST. The reliability estimates are based on scores averaged over the relevant time interval. The ICC values range from 0.22 to 0.97 across all seven BEAST variables for the first half, 0.30 to 0.96 for the second half and 0.25 to 0.95 over the total 90 minutes (full-time). The highest ICC value for the first half of the BEAST were obtained for 20 m sprint time ($r = 0.97$), and vertical jump ($r = 0.94$). The highest ICC value for the second half of the BEAST was for VJ ($r = 0.91$). The highest ICC value obtained over the total 90 minutes also was for VJ ($r = 0.93$). The lowest ICC value obtained for the first half, second half and full 90 minutes of the BEAST were those for shooting accuracy ($r = 0.22$, $r = 0.30$ and $r = 0.25$) and RPE ($r = 0.26$, $r = 0.64$ and $r = 0.44$).

Percent typical error values for the first half, second half and full-time range from 0.9 to 23.1%, 2.2 to 25.5% and 1.9 to 19.6% respectively. The lowest percent typical error values for the first half of the BEAST were those obtained for 20 m sprint time (0.9%),

12 m sprint time (1.8%), mean circuit time (2.4%) and mean HR (2.8%). Shooting accuracy (23.1%) and RPE (12.0%) exhibited the highest percent typical error for the first half of the BEAST.

The lowest percent typical error values for the second half of the BEAST were those for mean HR (2.2%), 12 m sprint time (3.2%), mean circuit time (3.2%) and 20 m sprint time (3.3%). The highest percent typical error values were those for shooting accuracy (25.5%) and RPE (9.9%).

The lowest percent typical error values for the overall BEAST were those for 20 m sprint time (1.9%), mean HR (2.1%) and 12 m sprint time (2.4%). Conversely, the highest percent typical error values were for shooting accuracy (19.6%) and RPE (10.4%).

There was a significant decrease in mean circuit time ($p<0.01$) for the first half (5.6 sec faster), second half (8.3 sec faster) and full-time (7 sec faster) from Trial 1 to Trial 2. Similarly, there was a significant decrease in VJ height ($p<0.05$) for the first half (1.6 cm), second half (1.8 cm) and full-time (1.7 cm) from Trial 1 to Trial 2. There was also a significant increase in goals scored (shooting accuracy) ($p<0.05$) for the second half (5.6) and full-time (8.2) during the second trial.

Table 6: *Test-retest reliability values for the BEAST protocol (Trial 1 versus Trial 2)*

Measure	Interval	Change in Mean (95% CI)	Typical Error (95% CI)	% Typical Error (95% CI)	ICC (95% CI)
Circuit Time (sec)	1 st half	-5.6	4.6	2.4	0.86
		(-9.24, -1.98)**	(3.39, 7.31)	(1.80, 3.8)	(0.62, 0.95)
	2 nd half	-8.3	6.5	3.2	0.78
		(-13.44, -3.25)**	(4.76, 0.25)	(2.4, 5.1)	(0.44, 0.92)
	Full time	-7.0	5.1	2.6	0.84
		(-10.95, -3.00)**	(3.72, 8.00)	(1.9, 4.1)	(0.58, 0.95)
12 m Sprint Time (sec)	1 st half	-0.01	0.04	1.8	0.89
		(-0.04, 0.02)	(0.03, 0.06)	(1.25, 2.90)	(0.65, 0.97)
	2 nd half	-0.02	0.07	3.2	0.69
		(-0.08, 0.04)	(0.05, 0.12)	(2.30, 5.37)	(0.22, 0.90)
	Full time	-0.01	0.05	2.4	0.80
		(-0.06, 0.03)	(0.04, 0.09)	(1.70, 3.97)	(0.45, 0.94)
20 m Sprint Time (sec)	1 st half	-0.01	0.03	0.9	0.97
		(-0.03, 0.01)	(0.02, 0.05)	(0.69, 1.49)	(0.92, 0.99)
	2 nd half	-0.01	0.11	3.3	0.68
		(-0.10, 0.08)	(0.08, 0.18)	(2.4, 5.1)	(0.25, 0.88)
	Full time	-0.01	0.06	1.9	0.88
		(-0.06, 0.04)	(0.05, 0.10)	(1.39, 3.02)	(0.66, 0.96)
VJ (cm)	1 st half	-1.6	1.8	4.5	0.94
		(-3.07, -0.13)*	(1.31, 2.91)	(3.24, 7.33)	(0.82, 0.98)
	2 nd half	-1.8	2.1	6.6	0.91
		(-3.41, -0.12)*	(1.54, 3.31)	(4.80, 10.62)	(0.74, 0.97)
	Full time	-1.7	1.8	5.3	0.93
		(-3.20, -0.20)*	(1.33, 2.96)	(3.78, 8.59)	(0.80, 0.98)
HR (b.min ⁻¹)	1 st half	-3.6	4.8	2.8	0.83
		(-8.19, 0.91)	(3.35, 8.40)	(1.97, 5.02)	(0.45, 0.95)
	2 nd half	-2.4	3.8	2.2	0.89
		(-6.25, 1.45)	(2.62, 6.94)	(1.51, 4.05)	(0.59, 0.97)
	Full time	-3.1	3.6	2.1	0.89
		(-6.77, 0.57)	(2.50, 6.62)	(1.43, 3.84)	(0.60, 0.97)
RPE	1 st half	1.5	12.0	12.0	0.26
		(1.13, 2.42)	(8.67, 19.62)	(8.67, 19.62)	(0.30, 0.68)
	2 nd half	-0.03	1.3	9.9	0.64
		(-1.05, 1.00)	(0.96, 2.06)	(7.15, 16.03)	(0.18, 0.87)

	Full time	-0.2 (-1.21, 0.88)	1.3 (0.97, 2.10)	10.4 (7.49, 16.84)	0.44 (-0.09, 0.78)
Shooting Accuracy	1 st half	2.1 (-2.09, 6.38)	5.2 (3.76, 8.36)	23.1 (16.23, 39.70)	0.22 (-0.35, 0.67)
	2 nd half	5.6 (1.23, 9.91)*	5.3 (3.86, 8.57)	25.5 (17.87, 44.11)	0.30 (-0.28, 0.71)
	Full time	8.2 (0.90, 15.53)*	9.0 (6.50, 14.44)	19.6 (13.83, 33.35)	0.25 (-0.33, 0.69)

Where: * = $p < 0.05$;

** = $p < 0.01$

Note: BEAST measures are all averaged over 45 minutes or 90 minutes

HR: Heart rate, VJ: Vertical jump, RPE: Rate of perceived exertion,

ICC: Intra-class Correlation Coefficient

4.1.2 Validity

The mean (\pm SD) number of circuits completed during the first 45 min half of Trial 2 for the Cr group was 14.2 ± 0.99 (5414 ± 376 m), and for the placebo group was 13.7 ± 0.84 (5224 ± 319 m). The mean number of circuits completed during the second 45 min half of Trial 2 for the Cr group was 14.0 ± 1.0 (5307 ± 391 m), and for the placebo group was 13.6 ± 1.0 (5173 ± 369 m). This equates to a total 90 minute distance of approximately 10721 ± 763 m for the Cr group and 10397 ± 681 m for the placebo group during the Trial 2 of the BEAST.

Over the 90 minute BEAST protocol, approximately 28 ± 2 circuits were completed. Of these 28 circuits, there were 55 ± 4 high-intensity sprints (887 ± 60 m), a total walking distance of 1941 ± 132 m, a total moderate to high-intensity (75% maximal effort) running distance of 3571 ± 242 m, and a total low to moderate-intensity running distance of 2717 ± 184 m. Players were also stationary for 1775 ± 120 s (~30 minutes) during the 90 minute protocol.

Total distance covered during the BEAST was significantly correlated to $\text{VO}_{2\text{max}}$ (Pearson's $r = 0.75$; $p < 0.01$) and Yo-Yo distance (Pearson's $r = 0.76$; $p < 0.01$). The total amount of high-intensity running covered during the BEAST was also significantly correlated with Yo-Yo distance ($r = 0.71$; $p < 0.03$).

Table 7 illustrates the subjects' mean heart rate (HR), heart rate peak (HR_{peak}), percent maximum heart rate (%HR_{max}), average VO₂ (VO_{2av}), peak VO₂ (VO_{2peak}) and percent VO₂ peak (%VO_{2peak}) of the BEAST respectively. HR_{av} and VO_{2av} were significantly lower during the second half compared to the first half.

Table 7: Mean and peak heart rate (HR) and VO₂ values for the first half, second half and full 90 minutes of BEAST protocol for Trial 2

Measure	First Half	Second Half	Full 90 min
HR	167.2 ± 10.5	163.7 ± 10.1*	165.9 ± 9.8
HR _{peak}	184.5 ± 7.7	181.3 ± 9.3	182.9 ± 7.7
% HR _{max}	86.0 ± 5.7	84.8 ± 5.3	85.4 ± 5.2
VO _{2av}	39.7 ± 3.5	38.5 ± 3.4*	39.2 ± 3.3
VO _{2peak}	45.5 ± 2.7	44.5 ± 3.1	43.5 ± 6.6
% VO _{2peak}	83.0 ± 14.5	81.0 ± 14.7	81.8 ± 14.4

Where: * $p < 0.05$; ** $p < 0.01$

4.2 STUDY TWO: The effect of acute Cr supplementation on soccer performance

Due to the poor reliability of RPE and shooting accuracy during the BEAST, these outcomes are not included in the results for Study 2.

4.2.1 Baseline characteristics of the study participants

Means, standard deviations (SD) and p-values for tests of statistically significant differences between the groups for the Yo-Yo and associated VO_{2max} variables are shown below in Table 8. There were no statistically significant differences between groups for these measures.

Table 8: Mean (\pm SD) baseline values of the Yo-Yo and VO_{2max} protocol for the two study groups

Variable	Creatine Group (n = 7)	Placebo Group (n = 8)	p ¹
Yo-Yo Level 1 (m)	1069 \pm 473	1065 \pm 387	0.98
VO_{2max} (ml.min ⁻¹ .kg ⁻¹)	46.7 \pm 7.2	50.6 \pm 6.1	0.28
VO_{2max} (L.min ⁻¹)	3.7 \pm 0.5	4.0 \pm 0.5	0.18

¹Independent samples t-test (equal variances not assumed).

Means, standard deviations and p-values for tests of statistically significant differences between the groups for the BEAST measures at Trial 2 (the pre-test) are shown in Table 9. Groups means exhibited are of subjects' mean scores averaged over the full 90 minute full-time BEAST protocol.

Table 9: Mean (\pm SD) Trial 2 (baseline) values of the BEAST variables for the two study groups

Variable	Creatine Group (n = 7)	Placebo Group (n = 8)	p ¹
Mean circuit time (s):	192 \pm 14	198 \pm 13	0.41
Mean 12 m sprint time (s)	2.16 \pm 0.14	2.20 \pm 0.09	0.49
Mean 20 m sprint time (s)	3.30 \pm 0.20	3.30 \pm 0.15	0.99
Mean vertical jump height (cm)	38.3 \pm 8.3	32.4 \pm 4.7	0.13

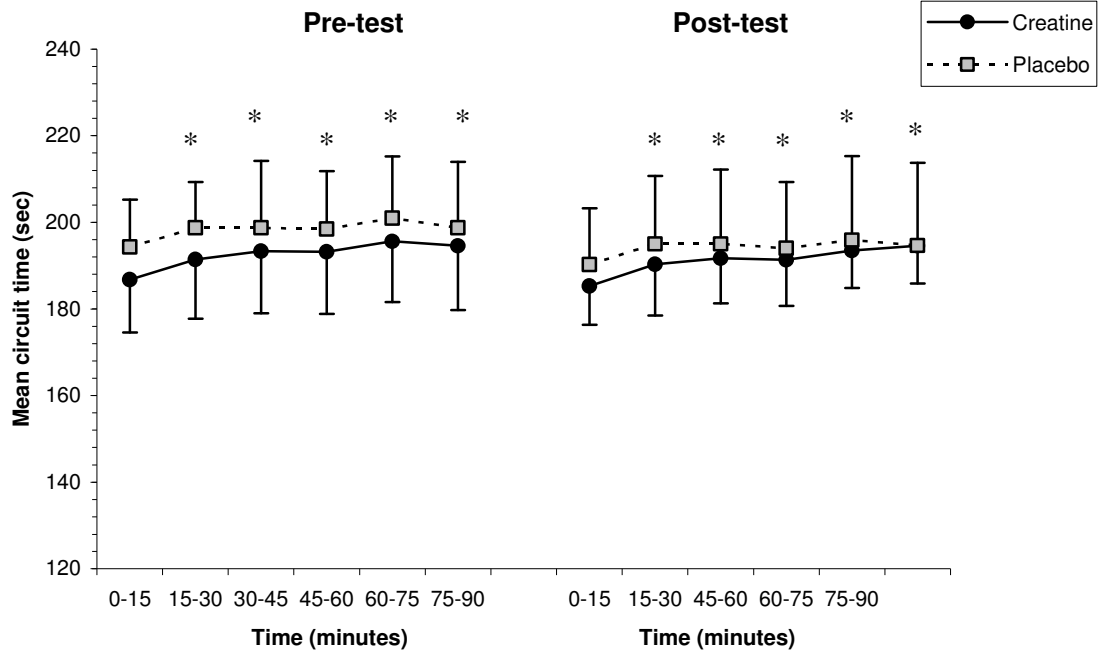
¹Independent samples t-test (equal variances not assumed).

All subjects tolerated the Cr supplementation protocol with no reports of gastrointestinal distress, medical problems or symptoms. In addition, there was no evidence of muscular cramping throughout the study.

4.2.2 BEAST performance measures

4.2.2.1 Mean circuit time

A repeated measures ANOVA (2 x 2 x 6) for mean circuit time, with Group as a between subjects factor and Trial and Interval (6 x 15 minute intervals) as within subjects factors showed no significant main effects for Group or Trial, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval). The lack of significant Group interactions with the Trial or Interval factors indicates that the groups did not differ significantly with respect to Trial or Interval effects, nor for any Trial*Interval interaction (refer Figure 5). However, there was a significant Interval main effect ($p < 0.001$) meaning that, ignoring Group and Trial effects, there were significant differences in mean circuit time amongst the six (15 min) intervals of the 90 minute protocol. Post-hoc comparisons showed that the second to sixth intervals (15-30, 30-45, 45-60, 60-75 and 75-90 min) each had significantly slower mean circuit times than the first interval (0-15 min). Compared to the first interval, the mean circuit time for interval six was, was on average 6.5 s (3.4%) slower (95% CI: 1.13, 11.88; $p = 0.012$; ES = -0.49). Compared to the first 45 minutes, the mean circuit time for the second 45 minutes was 2.9 s (1.5%) slower (95% CI: 1.04, 4.73; $p = 0.005$; ES = -0.22).



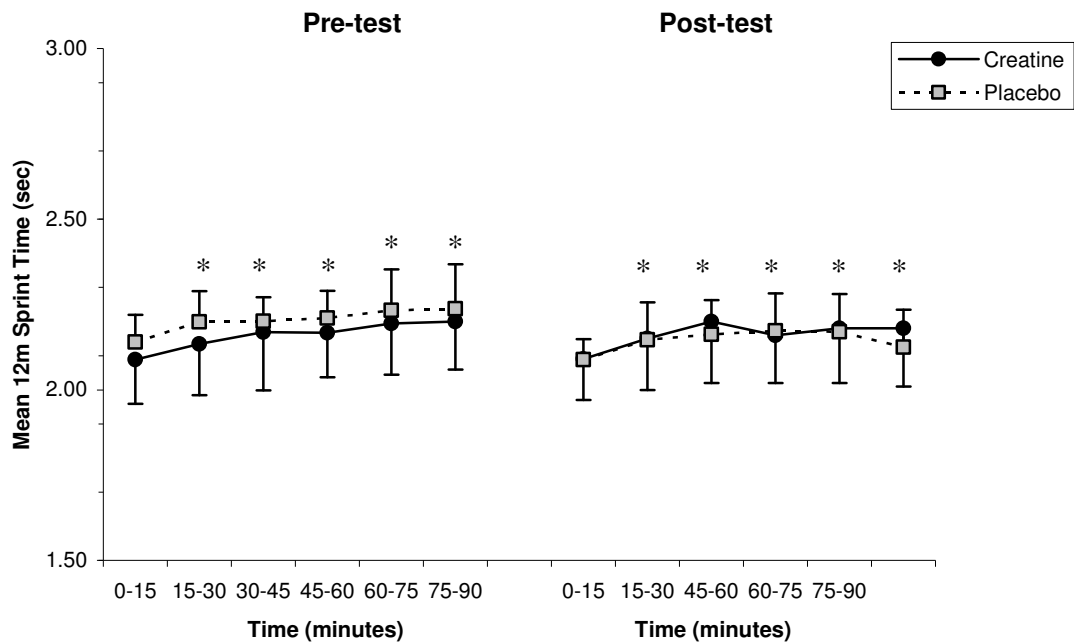
* Significant increase ($P<0.05$) from Interval 1 (0-15 min)

Figure 5: Mean (± 1 SD) 15-minute interval circuit times during the BEAST protocol pre and post-test for both the creatine and placebo groups

4.2.2.2 Mean 12 m sprint time

A repeated measures ANOVA ($2 \times 2 \times 6$) for mean 12 m sprint time, with Group as a between subjects factor and Trial and Interval (6 x 15 minute intervals) as within subjects factors showed no significant main effects for Group or Trial, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval) (refer Figure 6). However, there was a significant Interval main effect ($p<0.001$). Compared to the first interval (0-15 min), intervals two to six (15-30, 30-45, 45-60, 60-75 and 75-90 min) had significantly slower sprint times. When compared to the first interval, the mean time for interval six was 0.08 s (3.8%) slower (95% CI: 0.02, 0.15; $p = 0.01$; ES = -0.72). Compared to the first 45 minutes, the mean 12 m sprint time for

the second 45 minutes was 0.04 s (1.9%) slower (95% CI: 0.02, 0.06; $p = 0.001$, ES = -0.34).



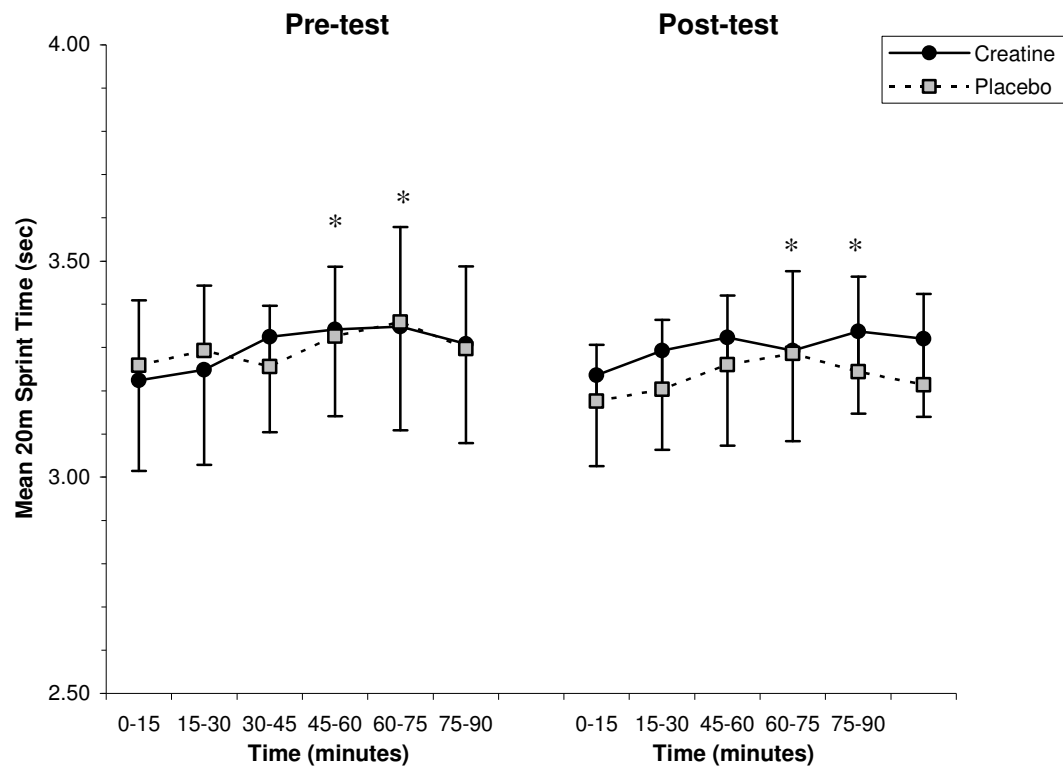
* Significant increase ($P < 0.05$) from Interval 1 (0-15 min)

Figure 6: Mean (± 1 SD) 15-minute interval 12 m sprint times during the BEAST protocol pre and post-test for both the creatine and placebo groups

4.2.2.3 Mean 20 m sprint time

A repeated measures ANOVA ($2 \times 2 \times 6$) for mean 20 m sprint time, with Group as a between subjects factor and Trial and Interval (6 x 15 minute intervals) as within subjects factors showed no significant main effects for Group or Trial, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval) (refer Figure 7). However, there was a significant Interval main effect ($p < 0.001$). Intervals four and five (45-60 and 60-75 min) had significantly slower mean sprint times ($p < 0.05$) compared to the first interval (0-15 min), with the fifth interval being on average 0.10 sec (3.1%) slower (95% CI: 0.002, 0.2; $p = 0.045$; ES = -0.55). When

compared to the first 45 minutes, the mean 20 m sprint time for the second 45 minutes was 0.05 s (1.5%) slower (95% CI: 0.01, 0.09; $p = 0.015$; ES = -0.27).

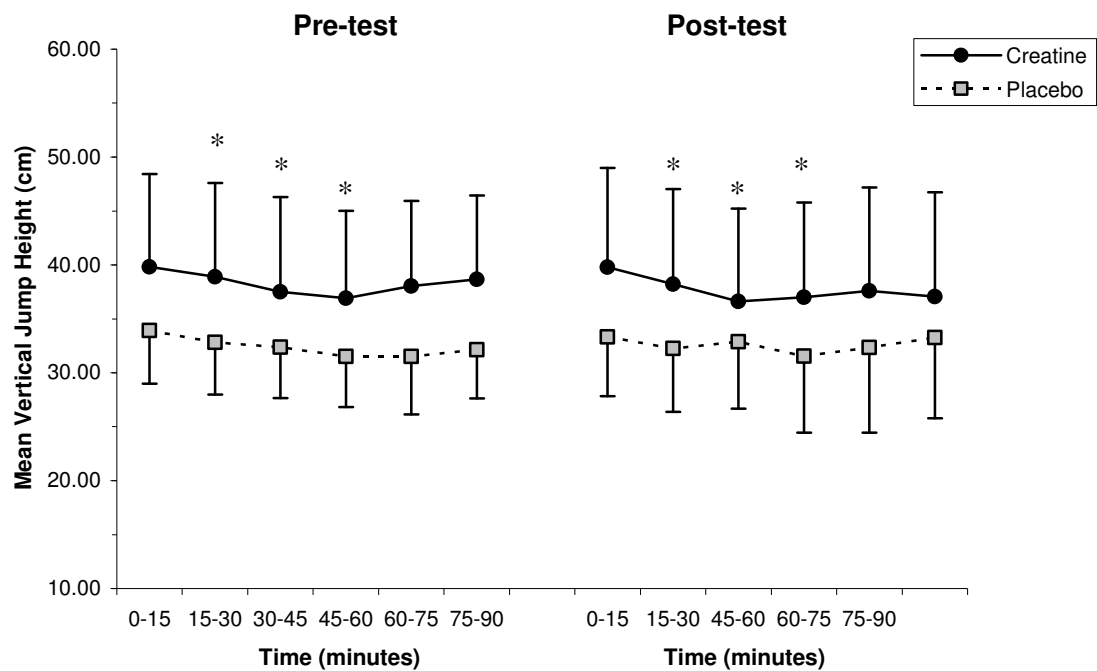


* Significant increase ($P < 0.05$) from Interval 1 (0-15 min)

Figure 7: Mean (± 1 SD) 15-minute interval 20 m sprint times during the BEAST protocol pre and post-test for both the creatine and placebo groups

4.2.2.4 Mean vertical jump height

A repeated measures ANOVA (2 x 2 x 6) for mean VJ height, with Group as a between subjects factor and Trial and Interval (6 x 15 minute intervals) as within subjects factors showed no significant main effects for Group or Trial, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval) (refer Figure 8). However, there was a significant Interval main effect ($p = 0.007$). Intervals two to four (15-30, 30-45, and 45-60 min) had significantly lower jump heights ($p < 0.05$) compared to the first interval (0-15 min) with the fourth interval (45-60 min) exhibiting a mean 2.46 cm (6.7%) reduction (95% CI: 0.80, 4.12; $p = 0.002$; ES = - 0.37). Compared to the first 45 minutes, the mean VJ height for the second 45 minutes decreased by 0.90 cm or 2.5% (95% CI: 0.15, 1.65; $p = 0.02$; ES = -0.14).



* Significant decrease ($P<0.05$) from Interval 1 (0-15 min)

Figure 8: Mean (± 1 SD) 15-minute interval VJ values during the BEAST protocol pre and post-test for both the creatine and placebo groups

4.2.2.5 Effect sizes and practical assessments of the effect of Cr (relative to placebo) on performance measures

As noted above, none of the Group**Trial* interactions tested by the repeated measures ANOVAs of the BEAST performance measures reached statistical significance. The effect sizes of Cr (relative to placebo) over the full 90 minute BEAST protocol and the chances that the true effect was substantial are shown in Table 10. As noted previously, the p-values entered into Hopkins' spreadsheet to obtain confidence intervals for the ES values and the chances that the true effect was substantial were drawn from ANOVA tests for a Group**Trial* interaction, and are equivalent to equal variance independent samples t-tests on group differences for post-pre change scores. A table based on p-

values derived from unequal variance t-tests yielded minimal differences to that shown, indicating homogeneous variance for the pre-post change scores (refer Appendix 7, Table 16).

Table 10: *Effect of creatine (relative to placebo) on performance measures of the 90 minute BEAST test expressed in Cohen units. Confidence limits, chances that the true effects were substantial and practical assessments of the effects are also shown.*

Performance measure	Cohen ES ¹	± 95% Confidence Limits	Chances that the true effect has substantial ² ...		
			Benefit %	Harm %	Practical Assessment ³
Circuit Time	-0.22	0.54	6	52	Unclear
12m Sprint	-0.53	0.69	2	84	Benefit very unlikely
20m Sprint	-0.39	0.59	3	75	Benefit very unlikely
VJ	-0.13	0.48	9	37	Unclear

¹ ES values are shown as positive where the effect of creatine is beneficial and negative where detrimental.

² Cohen ES ≥ 0.2 (Hopkins, 2002c)

³ If chance of benefit or harm both >5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. (Stuart et al., 2005)

As noted, none of the Group*Trial*Interval interactions tested by the repeated measures ANOVAs of the BEAST performance measures attained statistical significance. The effect sizes of Cr (relative to placebo) on performance measures over the second half (45 min interval) of the BEAST and the chances that the true effect was substantial is shown in Table 11. As described in the statistical analysis section, the results are based on p-values derived from equal variance t-tests for group differences in change scores. Alternative analyses using the p-values derived from unequal variance t-tests yielded very similar results (refer Appendix 7, Table 17).

Table 11: *Effect of creatine (relative to placebo) on performance measures over the second half (45 min interval) of the BEAST test expressed in Cohen units. Confidence limits, chances that the true effects were substantial and practical assessments of the effects are also shown.*

Performance measure	Cohen ES ¹	± 95% Confidence Limits	Chances that the true effect has substantial ² ...		
			Benefit %	Harm %	Practical Assessment ³
Circuit Time	-0.06	0.43	11	25	Unclear
12m Sprint	0.04	0.49	25	15	Unclear
20m Sprint	0.06	0.73	34	23	Unclear
VJ	-0.15	0.49	7	42	Unclear

¹ ES values are shown as positive where the effect of creatine is beneficial and negative where detrimental

² Cohen ES ≥ 0.2 (Hopkins, 2002c)

³ If chance of benefit or harm both >5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain (Stuart et al., 2005)

4.2.3 Other measures

4.2.3.1 Mean heart rate

A repeated measures ANOVA (2 x 2 x 2) for mean HR, with Group as a between subjects factor and Trial and Interval (2 x 45 minute intervals) as within subjects factors showed no significant Group or Trial main effects nor significant interactions (refer Appendix 7, Figure 11). There was however, a significant main effect for the Interval factor ($p = 0.002$) with subjects showing an average decrease in mean HR of $4.01 \text{ b}\cdot\text{min}^{-1}$

¹ (2.4%) in the second half (45 minutes) of the two 90 minute tests. (95% CI: 1.79, 6.24; $p = 0.013$ ES = 0.41).

4.2.3.2 Mean body-mass

Table 12 shows pre-trial, half-time and full-time mean body-mass values for the Cr and placebo group, pre (Trial 2) and post (Trial 3) supplementation.

A repeated measures ANOVA (2 x 2 x 3) for body-mass, with Group as a between-subjects factor and Trial and Interval as within subjects factors, showed no significant Group or Trial main effects, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval). There was however, a significant main effect for the Interval factor ($p < 0.001$). Compared to the pre-trial body-mass, the full-time body-mass of subjects reduced on average by 1.21 (95% CI: 1.01, 1.41; $p < 0.001$; ES = -0.13) kg (1.5%) over the 90 minute test and 0.83 (95% CI: 0.66, 1.01; $p < 0.001$; ES = -0.09) kg (1.0%) during the first 45 minutes.

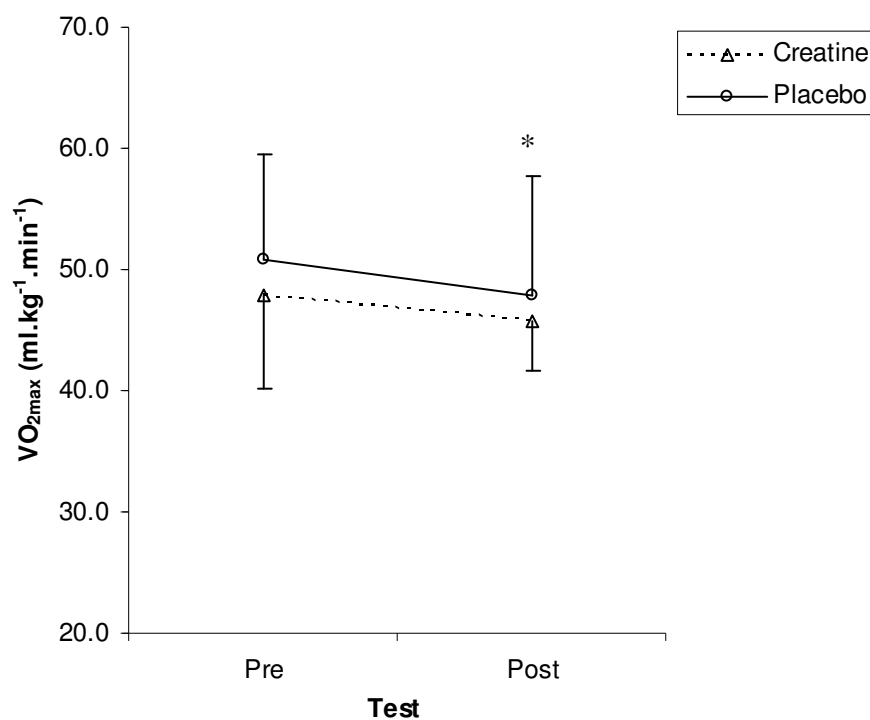
Table 12: Subjects mean (\pm SD) body-mass values (kg) prior to, during and following BEAST Trials 2 and 3

	Before Supplementation (Trial 2)			After Supplementation (Trial 3)		
	Pre Trial	Half Time	Full Time	Pre Trial	Half Time	Full Time
Creatine (N=7)	79.8 (± 10.5)	78.6 (± 10.4)	78.3 (± 10.4)	79.7 (± 10.4)	79.0 (± 10.2)	78.6 (± 10.0)
Placebo (N=8)	80.8 (± 8.6)	79.8 (± 8.2)	79.4 (± 8.3)	81.0 (± 8.5)	80.1 (± 8.5)	79.7 (± 8.5)

Where: * $p < 0.05$; ** $p < 0.01$

4.2.3.3 Mean $\text{VO}_{2\text{max}}$

A 2 X 2 repeated measures ANOVA on $\text{VO}_{2\text{max}}$ data showed no significant main effect for Group nor a significant Group*Trial interaction (refer Figure 9). However, there was a significant Trial effect ($p = 0.04$) with both groups showing a mean $2.50 \text{ ml.kg}^{-1}.\text{min}^{-1}$ (5.1%) decrease in $\text{VO}_{2\text{max}}$ values following supplementation (95% CI: 0.20, 4.80; $p = 0.036$ ES = -0.38).



* Significant decrease ($P < 0.05$) from pre to post-test

Figure 9: Mean ($\pm 1\text{SD}$) pre and post-test $\text{VO}_{2\text{max}}$ scores for the creatine and placebo groups

CHAPTER FIVE: DISCUSSION

5.1 Study One: Reliability and Validity of the BEAST

5.1.1 Reliability

According to Atkinson and Nevill (1998), high reliability could be thought of as the amount of measurement error that is made acceptable for the practical use of a measurement tool. Many terms have been used in the literature over the years for “reliability”. These include “repeatability”, “reproducibility”, “consistency”, “agreement”, “concordance” and “stability” (Atkinsin & Nevill, 1998). High test-retest reliability is crucial in tests used for both scientific research and to monitor athletic performance (Sunderland, Cooke, Milne, & Nevill, 2006).

Three commonly employed and accepted test-retest measures of reliability were employed in this study; the ICC, SEM and change in the mean. In evaluating the reliability of the BEAST measures, it is emphasized that all reliability assessments are based on values averaged over the 45 minute halves of the protocol, or the full 90 minute test period. Since reliability can usually be improved by averaging replicate measures (Shrout, 1998) the obtained reliability estimates are probably better than would have been obtained using single measures.

Intraclass Correlation Coefficient is a ratio of the variance due to differences between subjects to the total variability of the data (Weir, 2005). It is a relative measure of reliability that can theoretically vary between 0 and 1.0, where an ICC of 0 indicates no reliability and an ICC of 1.0 indicates perfect reliability (Weir, 2005). The relative

nature of the ICC stems from the fact that its magnitude is dependent on the between-subject variability. Where subjects differ little from each other, ICC values are small even if trial-to-trial variability is small. However, if subjects differ markedly from each other, ICC values can be large even though trial-to-trial variability is large (Weir, 2005). In other words, low between-subject variability will serve to depress the ICC even if the differences between subjects' scores across test conditions are small. Thus, the ICC is context specific (Traub, 1991).

Although the dependence of the ICCs magnitude on between-subject variability has been used as a criticism of it as a measure of reliability (J. Bland & Altman, 1986), Weir (2005) argues that such criticism is unfair since the ICC is used to provide information regarding inferential statistical tests, not to provide an index of absolute error. More specifically, low ICCs attenuate correlations between measures and increase the risk of Type II errors. With low ICCs, more subjects are needed in a study in order for a given effect size to be significant.

There exists some controversy in the literature with regard to interpreting values of the ICC (Shrout, 1998). Revising an earlier attempt by Landis and Koch (1977) to formulate qualitative descriptors for various ICC values, Shrout (1998) provides the following guideline: 0.00 – 0.10 = Virtually none; 0.11 – 0.40 = Slight; 0.41 – 0.60 = Fair; 0.61 – 0.80 = Moderate ;0.81 – 1.00 = Substantial.

Employing these guidelines, when scores were averaged over the full 90 minute protocol, five of the seven BEAST variables can be regarded as “substantially” reliable

(ICC >0.80). Of the two remaining measures, RPE (ICC = 0.44) had “fair” reliability and shooting accuracy (ICC = 0.25) had “slight” reliability.

The standard error of measurement (SEM) is another widely employed measure of reliability. Unlike the ICC, the SEM is an absolute (not relative) measure of reliability or trial-to-trial error in the data. For this reason an examination of the SEM in conjunction with the ICC is recommended (Weir, 2005). Further, because its interpretation centres on the assessment of reliability within individual subjects, it is of special relevance to practitioners (Weir, 2005). Hopkins (2002g) advocates use of the SEM which he refers to as the “typical error of measurement” or simply “typical error”. Closely related to the SEM is the coefficient of variation (CV), which is the typical error expressed as a percent of the subject’s mean score. It is particularly useful for representing the reliability of athletic events or performance tests (Hopkins, 2002g). Hopkins views typical error as being the “noise” or the uncertainty in the change measured, and the “signal” as the smallest worthwhile change. In a recent paper dealing with the issue of monitoring an athlete’s performance from test to test, Hopkins (2004) notes that there is no direct relationship between fitness-test performance and team performance in team sports. He therefore suggests that for team athletes an appropriate default for the smallest worthwhile change in test performance is a one-fifth change of the between-athlete standard deviation (a Cohen effect size of 0.2). Ideally, for monitoring the progression of individual team athletes on fitness tests the noise (typical error) of the test should be less than 0.20*between-athlete standard deviation (Hopkins, 2004). Hopkins notes that this ideal is rarely achieved however, with the noise of most performance tests being greater than the smallest worthwhile change. Although this makes assessment of changes in performance of the individual athlete problematic, he

suggests several solutions, including use of systematic rules to decide whether the true change is beneficial, trivial, harmful or unclear.

In evaluating the typical errors of the BEAST measures in this study, it is again emphasised that the values reported in this study are derived from average scores, not single assessments. For the full 90 minute BEAST protocol, four out of the seven variables had CV's less than 5% (mean circuit time, 2.6%; 12 m sprint time, 2.4%; 20 m sprint time, 1.9%; HR, 2.1%), one between 5% and 7.5% (VJ, 5.3%) and two greater than 10% (RPE, 10.4% and shooting accuracy, 19.6%). Hopkins (2004) provides graphical data for typical mean power of various types of athletic performance tests with most values ranging between 1% and 10%. Five of the seven BEAST performance measures are measures of mean power and their percentage typical errors (albeit involving averaged values) similarly fall within this range.

With regard to the relationship between noise and signal, Table 13 depicts the typical errors of the seven BEAST variables in relation to the smallest worthwhile change as advocated by Hopkins. Although none of the seven outcomes achieved a noise value less than the signal, four had typical errors between one and two times the size of the smallest worthwhile change. This bodes well for soccer coaches intending to use this protocol for monitoring changes in playing performance.

Table 13: *Noise, signal and noise / signal ratio for all seven full-time (90 min) averaged BEAST variables*

Variable	Noise (typical error)	Signal (0.2*between- subjects SD)	Noise/Signal Ratio
Circuit time	5.08	2.54	2.00
12m Sprint	0.05	0.02	2.50
20m Sprint	0.06	0.04	1.50
HR	3.63	2.59	1.40
VJ	1.84	1.44	1.28
RPE	1.33	0.38	3.50
Shooting	8.96	1.45	6.18

Systematic changes in the mean occur for a variety of reasons, including learning, fatigue, motivation and training effects (Hopkins, 2000). Hopkins argues that although systematic changes may seem unimportant in controlled trials since it is the differing effects for the groups that provide evidence for an effect, the magnitude of the systematic change is likely to differ between subjects, thereby increasing the typical error and correspondingly reducing the test reliability.

Three of the seven measures of the full 90 minute BEAST protocol exhibited statistically significant changes in their means from the first to the second trial. Mean circuit time decreased by 7.0 s (95% CI = -10.95, -3.00; ES = 0.55), VJ height decreased by 1.7 cm (95% CI = -0.32, -0.20; ES = 0.24) and shooting accuracy increased by 8.2 points (95% CI = 0.90, 15.53; ES = 0.88). The improvements for mean circuit time and shooting accuracy suggest that additional familiarisation trials may have been beneficial.

In comparison to previously published reliability data for similar protocols, the present reliability data compares reasonably well for most measures. Reliability of previous soccer simulated performance protocols are illustrated below in Table 14.

Table 14: *Reliability of soccer simulated performance protocols*

Soccer Test	Typical Error	Coefficient of Variation (CV)	Correlation Coefficient	Limits of Agreement
<i>Krustrup et al (2003)</i>				
Yo-Yo (level 1)		4.9%	$r = 0.98$	N/A
<i>Muller et al (1992)</i>				
Soccer-specific Endurance Test	N/A		Rank (Spearman) $r = 0.86$ Product-moment $r = 0.90$	N/A
<i>Nicolas et al (2000)</i>				
LIST	N/A		N/A	Run time part A: - 3.19 to 2.16 mins Sprint time part B: - 0.14 to 0.12 sec
<i>Sunderland et al (2006)</i>				
Field Hockey Skill Test	Men = 0.28 s Women = 0.26 s		Pearson $r = 0.96$ ICC $r = 0.96$	

5.1.2 Validity

Validity of measurement indicates the degree to which the scores from a test, or instrument, measures what it is supposed to measure (Thomas, Nelson, & Silverman, 2005). There are many kinds of validity used in the sport sciences. The four basic types are logical, content, criterion and construct validity (Thomas et al., 2005). We are concerned with logical validity (also known as face validity) as it provides a narrative or verbal defence of an instrument, and particularly if the instrument is one of a kind, then it cannot be compared to another measure (Courier, 1984).

All of the validity data were determined employing baseline (pre Cr supplementation or Trial 2 data) for both groups. The total mean (\pm SD) distance covered by both the Cr and placebo group over the full 90 minute BEAST was 10721 ± 763 m and 10397 ± 681 m respectively. For comparison, it has been reported that the distance covered in a real 90 minute soccer game ranges from 8638 m to 11527 m (Bangsbo & Lindquist, 1992; Bangsbo et al., 1991; Helgerud et al., 2001; Krstrup et al., 2005; Mohr et al., 2003; Rienzi et al., 2000; Thatcher & Batterham, 2004; Van Gool et al., 1988; Withers et al., 1982). The large variance in these match distances is potentially due to the different game intensities; i.e. the faster the pace of the game; the higher the work-rate, the greater distance covered in a game (Rienzi et al., 2000), environmental conditions, fitness of players i.e. players with a higher aerobic capacity will tend to have a higher work-rate and therefore cover greater distances than players with a lower aerobic capacity (Helgerud et al., 2001). It should be acknowledged that subjects used in the present study were of amateur club level only (with moderate aerobic capacities, refer to Figure 10), and were not considered “elite”; unlike most soccer players with a high VO_{2max} as used in previous match analysis studies e.g. 58.1 to 61.9 ml.kg.min⁻¹

(Bangsbo et al., 1991; Helgerud et al., 2001). Further work could establish whether the BEAST total distance correlated well with the actual distance covered during typical game play, and whether the total distance covered during the BEAST is determined by the physical performance abilities of player.

In previous work (Krustrup et al., 2003), the Yo-Yo test has been shown to be correlated to the total distance covered during a soccer game ($r = 0.52$; $p < 0.05$) and the amount of high-intensity running during a soccer match ($r = 0.71$; $p < 0.05$). To determine if this was the case for the simulated match-play BEAST protocol, the same relationship was assessed. In agreement with Krustrup et al (2003), the total distance covered during the BEAST correlated strongly with Yo-Yo distance ($r = 0.76$; $p < 0.01$) and the VO_{2max} scores ($r = 0.71$; $p < 0.01$), suggesting that athletes with a higher ability to perform repeated bouts of high-intensity exercise will cover a greater distance in the BEAST (and presumably in actual match play) than those with lower scores for these two measures. This finding illustrates the usefulness of the measurement of aerobic abilities in either laboratory (VO_{2max}) and field (Yo-Yo) tests in team sport athletes. Furthermore, given such observed relationships, the current findings illustrate that the BEAST is a useful protocol for match play simulation. The total amount of high-intensity running covered during the BEAST was also correlated with the total Yo-Yo distance ran ($r = 0.71$; $p < 0.03$), indicating that the greater the high-intensity running during the BEAST, the greater the distance covered in the Yo-Yo test.

Over the 90 minute BEAST protocol, approximately 28 ± 2 circuits were completed. During these circuits, there were 55 ± 4 high-intensity sprints (a distance of 887 ± 60 m), a total walking distance of 1941 ± 132 m, a total moderate to high-intensity (75% maximal effort) running distance of 3571 ± 242 m, and a total low to moderate intensity

running distance of 2717 ± 184 m. Players were also standing stationary for 1775 ± 120 s (~30 minutes) during the 90 minute protocol. Motion analysis studies have shown top-class soccer players sprint, on average, a total distance of 650 to 771 m (Bangsbo et al., 1991; Mohr et al., 2003; Van Gool et al., 1988), walk a total distance of 2427 to 4320 m (Bangsbo et al., 1991; Rienzi et al., 2000; Thatcher & Batterham, 2004), run at a moderate to high-intensity a total distance of 788 to 1536 m (Bangsbo et al., 1991; Thatcher & Batterham, 2004) and run at a low intensity (jog) a total distance of 3650 to 5207 m (Bangsbo et al., 1991; Rienzi et al., 2000; Thatcher & Batterham, 2004) during a real soccer match. The duration elite players stand stationary during a soccer match ranges from 472 to 918 s (Bangsbo et al., 1991; Mayhew & Wenger, 1985; Thatcher & Batterham, 2004). Thus, overall, the present data (demands and movements performed in the BEAST) compares well to that observed during soccer matches.

Whilst the BEAST protocol had similar total sprint distances and low to moderate intensity running distances to those performed during a 90 minute soccer match, the total moderate to high-intensity running distance and total standing time during the BEAST were both greater than the total moderate to high distances and total standing times previously recorded during soccer match analysis studies (Bangsbo et al., 1991; Mayhew & Wenger, 1985; Thatcher & Batterham, 2004). The total walking distance during the BEAST was less than the total walking distances observed during a soccer match. Despite these differences, it should be acknowledged that only minor adjustments in time per station / circuit are needed for a large end effect. For example, if the eight rest stations in the BEAST were reduced by only 1 s (seven seconds in duration instead of eight seconds), and one of the 10 m 75% maximal run stations were limited to 50% maximal running velocity during the BEAST protocol, a more comparable total rest (stationary) time and low-to-moderate and moderate-to-high-

intensity distance would have been achieved. Clearly, such modifications can easily be implemented for future testing using the BEAST protocol.

A soccer players mean HR during match play can range from 81.7 - 93.6% of %HR_{max} (Bangsbo et al., 2006; Helgerud et al., 2001; Krstrup et al., 2005; Krstrup et al., 2006; Mohr et al., 2004; Strøyer et al., 2004; Thatcher & Batterham, 2004; Van Gool et al., 1988) and mean HR range from ~156 - 167 b.min⁻¹ depending on the level of the player (Ali & Farrally, 1991; Bangsbo, 1994b; Krstrup et al., 2005; Krstrup et al., 2006; Mohr et al., 2004; Strøyer et al., 2004; Thatcher & Batterham, 2004; Van Gool et al., 1988). Krstrup et al (2005, 2006) reported mean peak HR of 187 b.min⁻¹ and 186 b.min⁻¹ during a soccer match respectively. Mean %HR_{max} of the BEAST was 85 ± 5 %, mean HR was 166 ± 10 b.min⁻¹ and mean peak HR was 183 ± 8 b.min⁻¹. These BEAST mean HR results are shown to be within the range of those found during a typical soccer match. Therefore, we can conclude that the BEAST appears to have a similar physiological load to that encountered during real soccer match play.

Some studies have illustrated the differences in mean HR between halves (first half versus second half) in a soccer match. Recently, Mohr et al., (2004) conducted a study on Danish fourth division soccer players and found mean HR were significantly higher ($p < 0.05$) in the first half (164 ± 1 b.min⁻¹) of the soccer match compared to the second half (158 ± 1 b.min⁻¹). This was also the case for previous studies by Stroyer (2004), Helgerud et al., (2001) and Ali & Farrally (1991). The mean HR of the BEAST was also found to be significantly higher ($p < 0.05$) in the first half (167 ± 11 b.min⁻¹) compared to the second half (164 ± 10 b.min⁻¹). The decline in mean HR during the second half was most likely due to a combination of glycogen depletion and dehydration, resulting in fatigue. Most players (especially non-elite) usually go “all

out” in the first half of a match and find it difficult to maintain this high work rate throughout the second half due to decreased glycogen and PCr levels, hence a drop-off in mean HR (Helgerud et al., 2001).

At the elite level, outfield player $\text{VO}_{2\text{max}}$ values can range anywhere from 58 to 61 $\text{ml.kg}^{-1}.\text{min}^{-1}$ (Bangsbo et al., 1991; Davis et al., 1992; Raven et al., 1976; Reilly et al., 2000). It has been reported that soccer players can maintain approximately 75 to 77% $\text{VO}_{2\text{max}}$ for the duration of a 90 minute game (Krustrup et al., 2005; Van Gool et al., 1988). Due to the difficulty in measuring actual VO_2 during match play, Bangsbo (1994) believes it is reasonable to suggest the mean relative work rate in a soccer game is around 70% $\text{VO}_{2\text{max}}$. Further more, Bangsbo (1994) noted that the VO_2 determined from HR measurements during a soccer match is potentially overestimated, due to factors such as static muscle contractions, emotional and heat stress. Using the VO_2 -HR relationship approach to estimate % $\text{VO}_{2\text{max}}$ during the BEAST, it was determined that players utilised approximately 82% of their $\text{VO}_{2\text{max}}$. As Bangsbo (1994) noted, this predicted value is perhaps overestimated, and we could assume the % VO_2 to be closer to that found in a real soccer match (~75% $\text{VO}_{2\text{max}}$).

Illustrated below in Table 15 are the distances covered, HR and $\text{VO}_{2\text{max}}$ values found during intermittent sports simulation protocols. Three of the nine intermittent sport protocols (Abt et al., 2003; Nicholas et al., 2000; Thatcher & Batterham, 2004) have replicated similar distances to those covered in a soccer match, four protocols have replicated the mean HR values (Cox, 2002; Drust et al., 2000; Nicholas et al., 2000; Thatcher & Batterham, 2004) found during a soccer match and two protocols have replicated similar mean % $\text{VO}_{2\text{max}}$ values found during a soccer match. However, very few (Nicholas et al., 2000; Thatcher & Batterham, 2004) have replicated all three values

(distance, mean HR and mean % $\text{VO}_{2\text{max}}$) observed during a soccer match: of these, was a field test; (Nicholas et al 2000), and one a treadmill test; (Thatcher & Batterham 2004). Although these two protocols have replicated three important measures, they do have limitations. Nicholas et al's (2000) full LIST protocol did not have the appropriate duration of a soccer game (~90 minutes), as it was only 75 minutes. Additionally, apart from turning, this protocol did not include any other movement or ball-skill activities relevant to soccer, such as shooting, jumping, sideways movements or passing. A limitation of Thatcher & Batterham's (2004) full SSEP was that it was performed on a treadmill; therefore no agility, turning, sideways movements, jumping or ball-skills could be integrated into it. The BEAST appears to be a more valid measure of soccer performance than either of these two tests, as the distance, duration, and HR values are all representative of a soccer match as well as having soccer-specific movements (e.g. jumping, agility) and ball-skills incorporated into it. The BEAST also has good reliability (refer section 5.1.1).

Table 15: Distances covered and the physiological load of different intermittent team performance tests and game simulation protocols.

Ref	Protocol (sport/mode)	Distance Covered (m)	HR (mean & peak)	% VO _{2max}
<i>Abt et al</i> (2003)	Non-motorised treadmill protocol	10196	unknown	unknown
<i>Bangsbo & Lindquist</i> (1992)	The Bangsbo Field Test	1900	unknown	unknown
<i>Cox et al</i> (2002)	Soccer Test	unknown	Mean HR = 174 b.min ⁻¹	unknown
<i>Drust et al</i> (2000)	Soccer-specific Treadmill Test	unknown	Mean HR = 168 b.min ⁻¹	68%
<i>Krustrup et al</i> (2003)	Yo-Yo (level 1)	1793	Mean HR @ 1,720 m = 181 b.min ⁻¹ Peak HR = 197 b.min ⁻¹	unknown
<i>Muller et al</i> (1992)	Soccer-specific Endurance Test	1640	Mean and peak HR = unknown	unknown
<i>Nicolas et al</i> (2000)	LIST	12400 (Part A+B)	Mean HR Part A = 169 & 171 b.min ⁻¹ Mean HR Part B = 175 & 176 b.min ⁻¹	70%
<i>Stuart et al</i> (2005)	Rugby Test	unknown	unknown	unknown
<i>Sunderland et al</i> (2006)	Field Hockey Skill Test	unknown	unknown	unknown
<i>Thatcher & Batterham</i> (2004)	SSEP	9924	First and second half = 166 b.min ⁻¹ (83% HRmax)	70%

In summary, the BEAST protocol replicated similar distances and mean and peak HR values, as well as having an aerobic workload ($\%VO_{2\max}$) similar to that observed during a soccer match. What makes the BEAST different from previous soccer protocols is that it incorporated a range of soccer-specific movements and ball-skills, which allows a closer energetic / muscular replication of real soccer match play. The soccer ball-skills provide a psychologically / motivating element that ensures subjects remain motivated and focussed throughout the full 90 minutes.

5.2 Study Two: The effect of acute Cr supplementation on soccer performance

The aim of the second study of this thesis was to determine the effects of acute short-term creatine (Cr) ingestion (1 week) on soccer performance, the latter being assessed by the BEAST protocol.

5.2.1 Baseline

Comparison of the two groups (Cr and placebo) prior to Cr supplementation revealed no significant differences in any of the BEAST performance measures (Table 9), $\text{VO}_{2\text{max}}$ or Yo-Yo performance scores (Table 8). The scores for all physical tests were within the expected range for this standard of player (Stolen, Chamari, Castagna, & Wisloff, 2005). However, despite no differences between the groups reaching statistical significance, it was observed that some imbalances existed with the placebo group having a somewhat higher $\text{VO}_{2\text{max}}$ and a lower mean VJ height. In view of such imbalances, plots of change scores against the pre-test values were examined according to the recommendations of Hopkins (2002e), to ensure a similar magnitude of change across the range of pre-test values. Such plots revealed uniformity of error.

5.2.2 Interval main effects

The change in physical measures that were continuously measured during each circuit of the BEAST was examined at 15 min intervals. This allowed some quantification of fatigue during the 90 min protocol. When groups were collapsed across trials (Trial 2 and Trial 3), repeated measures ANOVA showed a significant main effect for the Interval factor in all four BEAST performance measures (mean circuit time, 12 m sprint

time, 20 m sprint time and VJ), and HR values. Mean circuit time and 12 m sprint time had significantly slower times for intervals two (2.5% and 2.6%), three (2.9% and 3.7%), four (2.6% and 3.5%), five (3.7% and 4.2%) and six (3.3% and 3.9%) compared to interval one. Twenty meter sprint time was significantly slower in intervals four (2.7%) and five (1.9%) compared to interval one and VJ was significantly lower in intervals two (3.2%), three (5.1%) and four (6.7%) compared to interval one. Additionally, performance deteriorated significantly during the second half of the BEAST compared to the first for each of the above four measures. Heart rate also decreased significantly during the second 45 minute interval. As anticipated, this suggests that players fatigued over the course of the 90 minute protocol (Figures 5 to 8, and 10). These results are in line with previous studies which have shown top class soccer players perform less high intensity running in the initial phase of the second half compared to the first half of a match (Mohr et al., 2003; Mohr et al., 2004). Progressive fatigue that occurs during high-intensity intermittent exercise (which is characteristic to many team sports, including soccer), has been attributed to the depletion of muscle glycogen, reductions in circulating blood glucose, hyperthermia, and the loss of body fluids (Mohr et al., 2003). Such a degree of fatigue during the BEAST (1.5 to 2.5% drop from 1st half to second half) could also have been due to these mechanisms, and potentially from a depletion of PCr and decreased pH (caused by increased hydrogen ions), which have both been associated with the state of fatigue in skeletal muscle, and the decline in muscle power during high-intensity exercise (Cooke et al., 1997).

Another Interval effect was the reduction in body-mass in both groups (1.2%) during the 90 minute performance of the BEAST. Krustup et al (2006) recorded body-mass before a soccer match, at half time and at full time on 31 fourth division Danish soccer players. Similar results to the current study were reported. Weight loss during the

game was 0.84 L, or 1.1% of body-mass. This reduction from pre to post-trial was probably due to water loss (through sweating, respiration and substrate metabolism) as studies have found male soccer players to lose approximately 1.0 to 1.2 L.h⁻¹ during competition (Rehrer & Burke, 1996).

5.2.3 Trial main effects

There were no trial main effects for any of the four BEAST performance measures, HR or body-mass. However, the repeated measures ANOVA showed a significant Trial main effect for the VO_{2max} variable, with aerobic performance for both groups decreasing by 5.1% post-supplementation. This substantial reduction in VO_{2max} appears physiologically improbable since players were three weeks into their competition phase at the time of post testing and therefore this degree of detraining is unlikely. Also, that this was not accompanied by a substantial change in Yo-Yo score (which is a test of aerobic fitness specific to team sports) would suggest there was possibly a technical issue with the metabolic gas analysis system. However, the system used to measure VO₂ has been validated for use in a previous study (Meyer et al., 2001) and every effort was made to regularly calibrate the gas analyser prior to each test to minimise any variability / error. Given this, the 5.1% drop in VO_{2max} is perplexing.

5.2.4 Group differences

The repeated measures ANOVAs revealed no significant Group*Trial or Group*Trial*Interval interactions for any of the four BEAST performance measures (mean circuit time, 12 m sprint, 20 m sprint and VJ), body-mass or HR values. This suggests that Cr had no performance effect over the 90 minute BEAST protocol, or with regards to reducing fatigue over the 90 minute protocol. There was also no Group*Trial

interaction for $\text{VO}_{2\text{max}}$ indicating Cr did not significantly influence (relative to placebo) aerobic capacity.

The results of the present study are in agreement with other soccer (Smart et al., 1998), team sport (Ahmun, 2005; Cornish et al., 2006; Miszko et al., 1998; Redondo et al., 1996), cycling (Deutekom et al., 2000) and tennis (Pluim et al., 2006) studies that have documented no statistically significant acute effect of short-term Cr supplementation on sprint performance. However, the present results oppose findings from other soccer performance studies (Cox, 2002; Izquierdo et al., 2002; Mujika et al., 2000; Ostojic, 2004), as well as other team sport (Ahmun, 2005; Izquierdo et al., 2002), cycling (Vandebuerie et al., 1998), squash (Romer et al., 2001), swimming (Grindstaff et al., 1997) and individual anaerobic sport studies (Dawson et al., 1995; Kocak & Karli, 2003; Skare, Skadberg, & Wisnes, 2001) reporting changes in sprint performance.

It is difficult to compare and contrast the current study to other previous soccer studies that have tested the effects of Cr on soccer performance, as they have not used a 90 minute soccer-specific protocol that integrates most demands found during a soccer game (jumps, turns, walking, running, sprinting etc). However, Smart et al (1998) investigated the effects of acute short-term (six days) Cr supplementation ($24 \text{ g}\cdot\text{day}^{-1}$) on repeated sprint performance using national league soccer players. Subjects undertook thirty maximal 20 m running sprints with 30 s rest in between sprints. The authors found no statistically significant effect from Cr on repeated sprint performance. Though the distances and duration of the sprints were similar to the sprints in the BEAST, there were no other soccer related activities in between the sprints (walking, jumping, shooting, agility movements etc), therefore we cannot fully relate the findings of this study to the current study.

Cox et al (2002) performed a similar (but shorter duration of >75 min) study, using 14 elite female soccer players who ingested 20 g.day⁻¹ of Cr for six days, then performed a soccer-specific simulation protocol consisting of five 12 minute exercise testing blocks. Each five testing blocks included eleven maximal 20 m running sprints, two agility runs, and one precision ball kicking drill separated by several recovery walks, jogs and runs. The repeated sprints were similar in distance and quantity to those performed in the BEAST. However, unlike the BEAST results, there were statistically significant differences between groups for the repeated sprint times. The key findings of this study were the improved performance in nine of the 55 repeated 20 m sprints, and improved agility times in six agility runs of blocks two to four (2.2%) in the Cr group post-test, despite an increase in body-mass (1.3%). The Cr group achieved consistently faster post-supplementation times between sprints 10 and 47, reaching statistical significance in nine out of 55 twenty meter sprints. It is possible that the subjects Cr stores were potentially higher in Cox's study than the current study, which could be a reason why Cox et al (2002) did find improvements in sprint times as well as increased body-mass. However, as no urinary analyses were undertaken in either of the above studies, or present one, it is unknown how full the subjects Cr stores were after supplementation, and if compliance was truly 100%. This issue makes it difficult to interpret the conflicting findings of these studies.

The mixed findings of acute short-term Cr supplementation on sprint performance make it difficult to accurately conclude Cr supplementation has any effect on sprint performance. More research on acute, short-term Cr supplementation using an appropriate 90 minute soccer simulation protocol is therefore needed.

Explosive leg power as measured by the VJ test was not affected by acute Cr supplementation during the BEAST protocol. This was also the case for Miszko et al (1998) and Mujika et al (2000) who found no change in VJ or counter movement jumps (CMJ) respectively, after acute short-term Cr ingestion. However, Ostojic (2004) examined the effects of acute Cr ingestion on younger soccer players for seven days, and documented VJ performance to increase by 10.8% in the Cr group post-test. Izquierdo et al (2002) reported CMJ values to also increase (5.1%) after acute short-term Cr supplementation. Izquierdo et al (2002) and Mujika et al (2000) measured urinary creatinine and reported a significant increase in creatinine post-supplementation (43% and 18% respectively). In Mujika et al's (2000) study, the experimental groups initial urinary creatinine levels were very high (215 mg.dL^{-1}) compared to that of the placebo groups (165 mg.dL^{-1}), thus indicating the experimental groups stores were already "topped up". Izquierdo et al's (2002) experimental groups' initial creatinine levels were only (141 mg.dL^{-1}). This explains why there was such a slight increase in urinary creatinine post supplementation (18%) compared to Izquierdo et al (2002). Perhaps if Mujika et al's (2000) experimental group had lower urinary creatinine levels pre-test, there could have been a clearer effect of Cr supplementation on jump performance. Also, if the current study had analysed urinary creatinine, more definitive conclusions could have been drawn.

One of the reported effects of Cr supplementation is an increase in body-mass (Ahmun, 2005; Deutekom et al., 2000; Izquierdo et al., 2002; Kocak & Karli, 2003; McNaughton et al., 1998; Miszko et al., 1998). However, such increases in body-mass in the present study was not observed which is consistent with some other studies (Cornish et al., 2006; Grindstaff et al., 1997; Pluim et al., 2006; Redondo et al., 1996). Why such inconsistent findings exist between studies, including the present study, is difficult to

explain but could be due to non-documented dietary changes by subjects during Cr supplementation. In addition, the four studies that did not find any significant differences in body-mass did not incorporate any urinary creatine analyses in their study. Urine Cr analyses allows investigators to determine whether the Cr stores after supplementation were increased (Cr appearance in urine suggest Cr stores are full). Therefore, it is unknown whether the subjects Cr stores were indeed full after the supplementation period. In the current study, urine samples were undertaken at the time of testing and frozen for later analysis, but were not analysed due to a lack of funding. Thus, at the present time, it can not be concluded if Cr stores were maximised after the supplementation period. However, if the subjects' Cr stores were found to be low, it could also potentially be due to individual variation (Cr levels differ for different individuals of different body-mass and training history) and / or lack of compliance with Cr ingestion (subjects being dishonest about their consumption during the experimental periods). These possible scenarios resulting in low Cr stores could also explain why there was no statistical difference between groups in soccer performance using the BEAST protocol (repeated sprint performance, vertical jumps).

Soccer is largely an aerobic sport, approximately 98% (Hoff & Helgerud, 2004), and a high aerobic capacity is essential to compete at the highest level, and to be able to repeatedly perform and recover from high-intensity exercise bouts. The non significant effect of Cr on VO_{2max} or mean circuit time during the BEAST is supported by other studies which have investigated the effects of short and long-term Cr ingestion on aerobic performance (Izquierdo et al., 2002; Reardon, Ruell, Fiatarone Singh, Thompson, & Rooney, 2006; Van Loon et al., 2003; Vandebuerie et al., 1998). The lack of change in aerobic capacity after acute short-term Cr supplementation seems logical from a physiological perspective since the aerobic energy system is not

dependent on high-energy phosphagens such as ATP and PCr, which are generally used for the maintenance of peak muscular force production in shorter, high-intensity exercise tasks such as jumping, sprinting etc (Redondo et al., 1996) and is hypothesised that Cr increases PCr and ATP resynthesis (Greenhaff et al., 1994) and decreases muscle relaxation time (Van Leemputte et al., 1999). Therefore, Cr supplementation would not have an effect on the aerobic system. An increase in the Yo-Yo test score post-test for the Cr group however was anticipated, as this test is a high intensity intermittent (with recovery) protocol. Physiologically, it could be assumed that subjects in the Cr group should have had an accelerated PCr recovery in between the running bouts during the Yo-Yo test due to the more freely available Cr for PCr resynthesis. It is therefore surprising that these effects were also not found. Perhaps after a greater supplementation duration (multiple weeks), changes in Yo-Yo test score may have been observed.

Given the widely reported benefit of Cr on strength / muscle power, it was anticipated that the decline in physical performance especially sprint and jump height would be offset after Cr supplementations. However this was not observed possibly due to low Cr stores post-supplementation.

5.2.5 Clinical significance

The non-equivalence of statistical significance and clinical importance has long been recognised, but confusion over their interpretation remains common (Altman & Bland, 1995). A statistically significant difference may be real but not necessarily important. On the other hand, if a difference is not statistically different, it may be real and important (M. Bland, 2000; Hopkins, 2001). According to Hopkins (2001),

probabilities of clinical significance should be reported, not just the probability that defines statistical significance. Hopkins illustrates how a set of data that has a statistically non-significant p-value of 0.20 can have an 80% chance of the effect being clinically beneficial, a 15% chance of being clinically trivial effect, and a 5% chance of being clinically harmful. Hopkins argues that such data should be published since the effect has a good chance of helping people (16 times more chance of being beneficial than harmful). If the chances of helping are considered too low or the risk of harming too high, more data can be gathered, but if that is not feasible other researchers can do additional work and meta-analyse the data to increase the differences between likelihoods of benefit and harm.

In consideration of the above, it was considered important to also consider the clinical significance of the data in addition to the statistical significant results identified by ANOVA techniques. The effect of acute Cr supplementation on the BEAST performance measures over the full 90 minutes and the second 45 minute half, and the chances that the true effect was substantial (≥ 0.2) are shown in Tables 10 and 11 respectively. Although 95% confidence limits around the effect sizes are shown to provide consistency with confidence intervals reported elsewhere in this thesis, Hopkins (2002f) advocates use of 90% confidence limits, both to prevent assessment of whether the effect is significant at the 5% level and to provide consistency with his assessment of true values falling below the lower 95% limit or above upper the 95% limit as very unlikely. When assessed for the whole 90 minute BEAST protocol, all effects were negative and, correspondingly, the chances of a detrimental effect were greater than the chances of a beneficial effect. This is important as it illustrates Cr to have a potentially greater chance to be detrimental than to be beneficial to performance. With regard to practical assessment, the chances of Cr having a beneficial effect were considered very

unlikely (1 to 5%) for 12 and 20 m sprint time. While the disparity between likelihoods of benefit versus harm for mean circuit time and vertical jump were insufficient for a clear assessment to be made, the likelihoods of a detrimental effect were 8.7 and 4.1 times greater for circuit time and vertical jump respectively.

With regard to the effect of Cr (relative to placebo) on the four BEAST performance measures for the second half compared to the first half of the BEAST protocol, presumably assessing fatigue (see Table 11), all observed effect sizes were trivial (< 0.2) and the associated confidence limits were relatively large. Further, the chances of benefit or harm were greater than 5% for all four measures, thus precluding any clear practical assessment of the effect of Cr on fatigue. It is hypothesised that when Cr is ingested by athletes, it supposedly resynthesises ATP at a faster rate (due to increased PCr stores) within the muscles after intermittent activity, and this is speculated to improve an individual's ability to recover (e.g. between and after multiple maximal effort sprints). However, this does not seem to be the case in the current study (Figures 5 to 8, and 10). As mentioned previously, it is unknown if the Cr stores were completely full in the subjects after seven days supplementation, and therefore this could influence the ability to offset fatigue over the 90 minute protocol.

5.3 Limitations

Although the study failed to find evidence in support of the research hypothesis, failure to reject the null hypothesis does not mean that the null hypothesis is true, only that there is insufficient evidence to reject it. In such an event consideration needs to be given of the power of the study, i.e. the probability that the test will correctly reject the null hypothesis. Power is a function of sample size, alpha level, and effect size (Hair,

Anderson, Tatham, & Black, 1998). Cohen (1977) recommends that studies be designed to include sample sizes sufficient to achieve power levels of at least 0.80. With regard to Cr effects over the whole 90 minute protocol, trivial to medium sized effects were observed for mean circuit time (-0.22), 12 m sprint time (-0.53), 20 m sprint time (-0.39) and VJ (-0.13) (refer Table 10). Using these effect sizes as estimates of the population values, with alpha level set at 0.05 and the current sample size ($N = 15$), the statistical power of this study to detect the three effect sizes deemed worthwhile (> 0.2) was: 0.13 for mean circuit time; 0.34 for mean 12 m sprint time; and 0.26 for mean 20 m sprint time. The power of the study to detect the smallest effect size considered worthwhile (i.e. 0.2) was: 0.12 for mean circuit time; 0.09 for mean 12 m sprint time; 0.10 for mean 20 m sprint time, and 0.14 for mean vertical jump height. To detect the smallest worthwhile effect size with power set at 0.80 and alpha set at 0.05, a total number of 184 subjects would have been required for mean circuit time, 334 subjects for 12 m sprint time, 244 subjects for 20 m sprint time and 142 subjects for VJ. Clearly, the power of this study was low, yet the predicted sample sizes are unrealistic for the field of research. This is a challenge for researchers in sports performance wanting to detect small changes. In such circumstances Rossi (1990, p.2) notes that “it is reasonable to suggest that, a priori, there was not a fair chance of rejecting the null hypothesis and that the failure to reject the null should not weigh so heavily against the alternative hypothesis”.

The subjects used in this study were of amateur club level only, (four players from the ‘first’ team and the remaining players from a lower reserve and third division grade). Perhaps if elite soccer players had been used in this study, a more consistent effort / work-rate could have been achieved at both trials. If this were so, the within-subject

variability may have been lower, the reliability of the tests would have been higher and the effect of Cr would have been clearer.

Urine samples were collected to ensure all the experimental subjects had ingested the Cr supplement given to them. However, due to the lack of funding, urine samples were collected but not analysed. Therefore, we cannot conclude with confidence that the PCr stores of those subjects ingesting Cr were completely full after the supplementation period.

5.4 Conclusion

The first study of this thesis determined the reliability and validity of a 90 minute soccer simulation protocol (BEAST). The BEAST protocol was found to be a reliable and valid simulator of soccer match-play in terms of time, movement patterns and physical demands (volume and intensity) and subsequently provided an opportunity to investigate the effects of acute Cr supplementation on soccer-specific physical measures. Overall, use of this protocol in future studies will allow an insight into the true effect of different supplementations and ergogenic aids on team sport performance rather than that gained from previous studies that have primarily examined the effect(s) of acute Cr supplementation (and other nutritional strategies) on physical performance measured either in isolation or using protocols that are not reflective of actual sporting demands / conditions.

The second study of this thesis determined the effects of acute (short-term) Cr supplementation on soccer performance as measured by the BEAST protocol. There were no statistically significant differences between groups for the four BEAST performance measures, body-mass, HR or $\text{VO}_{2\text{max}}$ values, suggesting there was no effect of Cr (relative to placebo) on the 90 minute BEAST protocol, body-mass, HR or aerobic performance, nor in regard to reducing fatigue over the 90 minutes. When the effects were assessed for the whole 90 minute BEAST protocol, all effects were negative and, correspondingly, the chances of a detrimental effect were greater than the chances of a beneficial effect. With regard to practical assessment, the chances of Cr having a beneficial effect on sprint speed were considered very unlikely (1 to 5%), and the effects on VJ and circuit time were “unclear”. With regard to the effect of Cr (relative to placebo) on the four BEAST performance measures for the second half compared to

the first half of the BEAST protocol, presumably assessing fatigue, all observed effect sizes were trivial (< 0.2).

Thus, whilst the current study supports the use of the BEAST for future simulation / intervention studies, it does not endorse the use of Cr supplementation for increasing physical performance during soccer. Further work may be required to investigate the effects of acute Cr supplementation in elite / professional soccer players, long-term Cr supplementation and physical performance in a variety of accurately simulated team sports where Cr may currently be advocated as a beneficial ergogenic aid.

REFERENCES

- Aaserud, R., Gramvik, P., Olsen, S. R., & Jensen, J. (1998). Creatine supplementation delays onset of fatigue during repeated bouts of sprint running. *Scandinavian Journal of Medicine and Science in Sports*, 8, 247-251.
- Abt, G. (2006). Ballsports Endurance And Sprint Test (BEAST). *Unpublished Manuscript, St Martin's College, UK*.
- Abt, G., Reaburn, P., Holmes, M., & Gear, T. (2003). Changes in peak sprint speed during prolonged high-intensity intermittent exercise that simulates team sport play. *Journal of Sports Sciences*, 21(4), 256-257.
- Ahmun, R., Tong, R., & Grimshaw, P. (2005). The effects of acute creatine supplementation on multiple sprint cycling and running performance in rugby players. *Journal of Strength and Conditioning Research*, 19(1), 92-97.
- Ali, A., & Farrally, M. (1991). Recording soccer players' heart rates during matches. *Journal of Sports Sciences*, 9, 183-190.
- Altman, D., & Bland, J. (1995). Absence of evidence is not evidence of absence. *British Medical Journal*, 311, 485.
- Atkinson, G., & Nevill, A. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, 26(4), 217-238.
- Balsom, P., Gaitanos, G., Soderlund, K., & Ekblom, B. (1999). High-intensity exercise and muscle glycogen availability in humans. *Acta Physiologica Scandinavica*, 165, 337-345.
- Balsom, P., Soderlund, K., & Ekblom, B. (1994). Creatine in humans with special reference to creatine supplementation. *Sports Medicine*, 18(4), 268-280.
- Bangsbo, J. (1994a). Energy demands in competitive soccer. *Journal of Sports Sciences*, 12, S5-12.
- Bangsbo, J. (1994b). The physiology of soccer - with special reference to intense intermittent exercise. *Acta Physiologica Scandinavica*, 151(Supp. 619), 1-155.
- Bangsbo, J., & Lindquist, F. (1992). Comparison of various exercise tests with endurance performance during soccer in professional players. *International Journal of Sports Medicine*, 13(2), 125-132.

- Bangsbo, J., Mohr, M., & Krstrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, 24(7), 665-674.
- Bangsbo, J., Norregaard, L., & Thorso, F. (1991). Activity profile of competition soccer. *Canadian Journal of Sport Science*, 16(2), 110-116.
- Beduschi, G. (2003). Current popular ergogenic aids used in sports: a critical review. *Nutrition Diet*, 60, 104-118.
- Bemben, M., Bemben, D., Loftiss, D., & Knehans, A. (2001). Creatine supplementation during resistance training in college football athletes. *Medicine & Science in Sports & Exercise*, 33(10), 1667-1673.
- Bemben, M., & Lamont, H. (2005). Creatine supplementation and exercise performance. *Sports Medicine*, 35(2), 107-125.
- Bishop, D., & Claudius, B. (2005). Effects of induced metabolic alkalosis on prolonged intermittent-sprint performance. *Medicine & Science in Sports & Exercise*, 37(5), 759-767.
- Bizzarini, E., & De Angelis, I. (2004). Is the use of creatine supplementation safe? *Journal of Sports Medicine and Physical Fitness*, 44(4), 411-416.
- Bland, J., & Altman, D. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 1, 307-310.
- Bland, M. (2000). *An introduction to medical statistics* (3rd ed.). Oxford: Oxford University Press.
- Branch, J., & Williams, M. (2002). Creatine as an ergogenic supplement. In *Performance enhancing substances in sport and exercise*. Champaign: Human Kinetics.
- Carling, C., Williams, A., & Reilly, T. (2007). *Handbook of soccer match analysis: A systematic approach to improving performance*. London, UK: Routledge.
- Clarkson, P. (1996). Nutrition for Improved Sports Performance. *Sports Medicine*, 21(6), 393-401.
- Cohen, J. (1977). *Statistical power analysis for the behavioural sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

- Cooke, S., Petersen, S., & Quinney, H. (1997). The influence of maximal aerobic power on recovery of skeletal muscle following anaerobic exercise. *European Journal of Applied Physiology*, 75, 512-519.
- Cornish, S., Chilibeck, P., & Burke, D. (2006). The effect of creatine monohydrate supplementation on sprint skating in ice-hockey players. *Journal of Sports Medicine and Physical Fitness*, 46, 90-98.
- Courier, D. (1984). *Elements of Research in Physical Therapy*. Baltimore: Williams & Wilkins.
- Cox, G., Mujika, I., Tumilty, D., & Burke, L. (2002). Acute creatine supplementation and performance during a field test simulating match play in elite female soccer players. *Journal of Sport Nutrition and Exercise Metabolism*, 12, 33-46.
- Davis, J., Brewer, J., & Atkin, D. (1992). Preseason physiological characteristics of English first and second division soccer players. *Journal of Sports Sciences*, 10, 541-547.
- Dawson, B., Cutler, M., Moody, A., Lawrence, S., Goodman, C., & Randall, N. (1995). Effects of oral creatine loading on single and repeated maximal short sprints. *The Australian Journal of Science and Medicine in Sport*, 27(3), 56-61.
- Deutekom, M., Beltman, J. G. M., de Ruiter, C. J., de Koning, J. J., & de Haan, A. (2000). No acute effects of short-term creatine supplementation on muscle properties and sprint performance. *European Journal of Applied Physiology*, 82, 223-229.
- Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine*, 28, 222-227.
- Drust, B., Reilly, T., & Cable, N. T. (2000). Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. *Journal of Sports Sciences*, 18, 885-892.
- Eklom, B. (1986). Applied physiology of soccer. *Sports Medicine*, 3, 50-60.
- Gaitanos, G. C., Williams, C., Boobis, L. H., & Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. *Journal of Applied Physiology*, 75(2), 712-719.
- Green, A., Simpson, E., Littlewood, J., MacDonald, I., & Greenhaff, P. (1996). Carbohydrate ingestion augments creatine retention during creatine feeding in humans. *Acta Physiologica Scandinavica*, 158, 195-202.

- Greenhaff, P. (1997). The nutritional biochemistry of creatine. *Journal of Nutritional Biochemistry*, 8, 610-618.
- Greenhaff, P., Bodin, K., Soderlund, K., & Hultman, E. (1994). Effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis. *American Journal of Physiology*, 266, E725-E730.
- Greenhaff, P., Casey, A., Short, A., Harris, R., Soderlund, K., & Hultman, E. (1993). Influence of oral creatine supplementation on muscle torque during repeated bouts of maximal voluntary exercise in man. *Clinical Science*, 84, 565-571.
- Grindstaff, P. D., Kreider, R., Bishop, R., Wilson, M., Wood, L., Alexander, C., et al. (1997). Effects of creatine supplementation on repetitive sprint performance and body composition in competitive swimmers. *International Journal of Sport Nutrition*, 7, 330-346.
- Hair, J., Anderson, R., Tatham, R., & Black, W. (1998). *Multivariate data analysis*. Upper Saddle River, NJ: Prentice Hall.
- Harris, R. C., Soderlund, K., & Hultman, E. (1992). Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. *Clinical Science*, 83, 367-374.
- Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise*, 33(11), 1925-1931.
- Hespel, P., Maughan, R. J., & Greenhaff, P. L. (2006). Dietary supplements for football. *Journal of Sports Sciences*, 24(7), 749-761.
- Hoff, J. (2005). Training and testing physical capacities for elite soccer players. *Journal of Sports Sciences*, 23(6), 573-582.
- Hoff, J., & Helgerud, J. (2004). Endurance and strength training for soccer players. *Sports Medicine*, 34(3), 165-180.
- Hoffman, J., Stout, J., Falvo, M., Kang, J., & Ratamess, N. (2005). Effect of low-dose, short-duration creatine supplementation on anaerobic exercise performance. *Journal of Strength and Conditioning Research*, 19(2), 260-264.
- Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, 30, 1-15.
- Hopkins, W. (2001). Clinical vs Statistical Significance. *Sportscience*, 5(3), 1.
- Hopkins, W. (2002a). *Difference in means*. Retrieved November 14th, 2006, from <http://www.sportsci.org/resource/stats/effect.html>

- Hopkins, W. (2002b). *A New View of Statistics*. Retrieved October 9th, 2006, from <http://www.sportsci.org/resource/stats/>
- Hopkins, W. (2002c). *Probabilities of clinical or practical significance*. Retrieved August 31st, 2006, from www.sportsci.org/jour/0201/wghprob.htm
- Hopkins, W. (2002d). *Slideshow on Repeated Measures*. Retrieved October 14th, 2006, from <http://www.sportsci.org/resource/stats/index.html>
- Hopkins, W. (2002e). *A spreadsheet for analysis of straightforward controlled trials*. Retrieved October 30th, 2006, from <http://www.sportsci.org/resource/stats/index.html>
- Hopkins, W. (2002f). *Statistical vs clinical or practical significance [slideshow]*. Retrieved November 14th, 2006, from http://www.sportsci.org/jour/0201/Statistical_vs_clinical.ppt
- Hopkins, W. (2002g). *Typical Error of Measurement*. Retrieved September 8th, 2006, from <http://www.sportsci.org/resource/stats/index.html>
- Hopkins, W. (2004). How to interpret changes in an athletic performance test. *Sportscience*, 8, 1-7.
- Hughes, M., Doherty, M., Tong, R., Reilly, T., & Cable, N. (2006). Reliability of Repeated Sprint Exercise in Non-Motorised Treadmill Ergometry. *International Journal of Sports Medicine*, 27, 900-904.
- Hultman, E., Soderlund, K., Timmons, J., Cederblad, G., & Greenhaff, P. (1996). Muscle creatine loading in men. *Journal of Applied Physiology*, 81(1), 232-237.
- Izquierdo, M., Ibanez, J., Gonzalez-Badillo, J., & Gorostiaga, E. (2002). Effects of creatine supplementation on muscle power, endurance and sprint performance. *Medicine & Science in Sports & Exercise*, 34(2), 332-343.
- Kocak, S., & Karli, U. (2003). Effects of high dose oral creatine supplementation on anaerobic capacity of elite wrestlers. *Journal of Sports Medicine and Physical Fitness*, 43, 488-492.
- Kreider, R., Ferreira, M., Wilson, M., Grindstaff, P., Plisk, S., Reinhardy, J., et al. (1998). Effects of creatine supplementation on body composition, strength and sprint performance. *Medicine and Science in Sports and Exercise*, 30, 73-82.
- Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., et al. (2003). The Yo-Yo Intermittent Recovery Test: Physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise*, 35(4), 697-705.

- Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: importance of training status. *Medicine & Science in Sports & Exercise*, 37(7), 1242-1248.
- Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. *Medicine & Science in Sports & Exercise*, 38(6), 1165-1174.
- Landis, J., & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33, 159-174.
- Maxwell, N., Aitchison, T., & Nimmo, M. (1996). The effect of climatic heat stress on intermittent supramaximal running performance in humans. *Experimental Physiology*, 81(5), 833-845.
- Mayhew, S., & Wenger, H. (1985). Time motion analysis of professional soccer. *Journal of Human Movement Studies*, 11, 49-52.
- McNaughton, L., Dalton, B., & Tarr, J. (1998). The effects of creatine supplementation on high intensity exercise performance in elite performers. *European Journal of Applied Physiology*, 78, 236-240.
- Metaxas, T., et al. (2005). Comparative study of field and laboratory tests for the evaluation of aerobic capacity in soccer players. *Journal of Strength and Conditioning Research*, 19(1), 79-84.
- Metzger, J., & Fitts, R. (1987). Role of intracellular pH in muscle fatigue. *Journal of Applied Physiology*, 66, 1392-1397.
- Meyer, T., Georg, T., Becker, C., & Kindermann, W. (2001). Reliability of Gas Exchange Measurements from Two Different Spiroergometry Systems. *International Journal of Sports Medicine*, 22, 593-597.
- Miszko, T., Baer, J., & Vanderburgh, P. (1998). The effect of creatine loading on body mass and verticle jump of female athletes. *Medicine & Science in Sports & Exercise*, 30(5), S141.
- Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, 21, 519-528.
- Mohr, M., Krustrup, P., Nybo, L., Jung Nielson, J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches - beneficial effect of a re-warm up at half-time. *Scandinavian Journal of Medicine and Science in Sports*, 14, 156-162.

- Mujika, I., Padilla, S., Ibanez, J., Izquierdo, M., & Gorostiaga, E. (2000). Creatine supplementation and sprint performance in soccer players. *Medicine and Science in Sports and Exercise*, 32(2), 518-525.
- Muller, E., Kornex, E., & Leitenstorfer, W. (1992). Soccer specific endurance test. *Leistungssport*, 22(2), 56-60.
- Nicholas, C. W., Nuttall, F. E., & Williams, C. (2000). The Loughborough Intermittent Shuttle Test: A field test that simulates the activity pattern of soccer. *Journal of Sports Sciences*, 18, 97-104.
- Nissen, S., & Sharp, R. (2003). Effect of dietary supplements on lean body mass and strength gains with resistance exercise: a meta-analysis. *Journal of Applied Physiology*, 94, 651-659.
- Ostojic, S. (2004). Creatine supplementation in young soccer players. *International Journal of Sport Nutrition and Exercise Metabolism*, 14, 95-103.
- Peyrebrune, M. C., Nevill, M. E., Donaldson, F., & Cosford, D. J. (1998). The effects of oral creatine supplementation on performance in single and repeated sprint swimming. *Journal of Sports Sciences*, 16, 271-279.
- Pluim, B., Ferrauti, A., Broekhof, F., Deutekom, M., Gotzmann, A., Kuipers, H., et al. (2006). The effects of creatine supplementation on selected factors of tennis specific training. *British Journal of Sports Medicine*, 40, 507-512.
- Preen, D., Dawson, B., Goodman, C., Beilby, J., & Ching, S. (1999). *A comparison of various creatine loading and maintenance protocols on total creatine accumulation in human skeletal muscle*. Paper presented at the 5th IOC World Congress on Sport Sciences, Sydney, Australia.
- Rampinini, E., Biship, D., Marcora, S., Sassi, R., & Impellizzeri. (2007). Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *International Journal of Sports Medicine*, 28, 228-235.
- Raven, P., Gettman, L., Pollock, M., & Cooper, K. (1976). A physiological evaluation of professional soccer players. *British Journal of Sports Medicine*, 10(4), 209-216.
- Rawson, E., Persky, A., Price, T., & Clarkson, M. (2004). Effects of repeated creatine supplementation on muscle, plasma, and urine creatine levels. *Journal of Strength and Conditioning Research*, 18(1), 162-167.

- Reardon, T., Ruell, P., Fiatarone Singh, M., Thompson, C., & Rooney, K. (2006). Creatine supplementation does not enhance submaximal aerobic training adaptations in healthy young men and women. *European Journal of Applied Physiology*, 98, 234-241.
- Redondo, D. R., Dowling, E. A., Graham, B. L., Almada, A. L., & Williams, M. H. (1996). The effect of oral creatine monohydrate supplementation on running velocity. *International Journal of Sport Nutrition*, 6, 213-221.
- Rehrer, N., & Burke, L. (1996). Sweat losses in various sports. *Australian Journal of Nutrition & Dietetics*, 53(4), S13.
- Reilly, T. (2005). An ergonomics model of the soccer training process. *Journal of Sports Sciences*, 23(6), 561-572.
- Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences*, 18, 669-683.
- Reilly, T., & Thomas, V. (1976). A motion analysis of work-rate in different positional roles in professional football match-play. *Journal of Human Movement Studies*, 2, 87-97.
- Reilly, T., & Williams, M. (2003a). Fitness Assessment. In T. Reilly & D. Doran (Eds.), *Science and Soccer* (2nd ed., pp. 21-46). London: Routledge.
- Reilly, T., & Williams, M. (2003b). Fitness assessment. In T. Reilly & D. Doran (Eds.), *Science and Soccer*. London: Routledge.
- Reilly, T., & Williams, M. (2003c). Introduction to science and soccer. In T. Reilly & M. Williams (Eds.), *Science and Soccer* (2nd ed., pp. 1-6). London: Routledge.
- Rienzi, E., Drust, B., Reilly, T., Carter, J., & Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness*, 40(2), 162-169.
- Romer, L. M., Barrington, J. P., & Jeukendrup, A. E. (2001). Effects of oral creatine supplementation on high intensity, intermittent exercise performance in competitive squash players. *International Journal of Sports Medicine*, 22, 546-552.
- Sahlin, K. (1992). Metabolic factors in fatigue. *Sports Medicine*, 13, 99-107.
- Schroder, H., Terrados, N., & Tramullas, A. (2005). Risk assessment of the potential side effects of long-term creatine supplementation in team sport athletes. *European Journal of Nutrition*, 44, 255-261.

- Shephard, R. (1999). Biology and medicine of soccer: An update. *Journal of Sports Sciences*, 17, 757-786.
- Shrout, P. (1998). Measurement reliability and agreement in psychiatry. *Statistical Methods in Medical Research*, 7, 301-317.
- Shrout, P., & Fleiss, J. (1979). Intraclass correlation: uses in assessing rater reliability. *Psychological Bulletin*, 86, 420-428.
- Skare, O., Skadberg, O., & Wisnes, A. (2001). Creatine supplementation improves sprint performance in male sprinters. *Scandinavian Journal of Medicine, Science and Sports*, 11, 96-102.
- Smart, N., McKenzie, S., Nix, L., Baldwin, S., Page, K., Wade, D., et al. (1998). Creatine supplementation does not improve repeat sprint performance in soccer players. *Medicine & Science in Sports & Exercise*, 30(5), S140.
- Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities. *Sports Medicine*, 35(12), 1025-1044.
- Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of Soccer: An Update. *Sports Medicine*, 35(6), 501-536.
- Stone, M. H., Sanborn, K., Smith, L. L., O'Bryant, H. S., Hoke, T., Utter, A. C., et al. (1999). Effects of in-season (5 weeks) creatine and pyruvate supplementation on anaerobic performance and body composition in American football players. *International Journal of Sport Nutrition*, 9, 146-165.
- Strøyer, J., Hansen, L., & Klausen, K. (2004). Physiological profile and activity pattern of young soccer players during match play. *Medicine and Science in Sports and Exercise*, 36(1), 168-174.
- Stuart, G., Hopkins, W., Cook, C., & Cairns, S. (2005). Multiple effects of caffeine on simulated high intensity team sport performance. *Medicine & Science in Sports & Exercise*, 37(11), 1998-2005.
- Sunderland, C., Cooke, K., Milne, H., & Nevill, M. (2006). The reliability and validity of a field hockey skill test. *International Journal of Sports Medicine*, 27, 395-400.
- Sundgot-Borgen, J., Berglund, B., & Torstveit, M. (2003). Nutritional supplements in Norwegian elite athletes - impact of international ranking and advisors. *Scandinavian Journal of Medicine, Science and Sports*, 13, 138-144.

- Terjung, R., Clarkson, P., Eichner, E., Greenhaff, P., Hespel, P., Israel, R., et al. (2000). The physiological and health effects of oral creatine supplementation. *Medicine & Science in Sports & Exercise*, 32(3), 706-717.
- Thatcher, R., & Batterham, M. (2004). Development and validation of a sport-specific exercise protocol for elite youth soccer players. *Journal of Sports Medicine and Physical Fitness*, 44, 15-22.
- Thomas, J., Nelson, J., & Silverman, S. (2005). *Research methods in physical activity* (5th ed.). Champaign: Human Kinetics.
- Traub, R. (1991). Understanding reliability. *Educational measurement, issues and practice*, 10, 37-45.
- Van Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *Journal of Physiology*, 513(1), 295-305.
- Van Gool, D., Van Gerven, D., & Boutmans, J. (1988). The physiological load imposed on soccer players during real match-play. In T. Reilly, A. Lees, K. Davids & W. J. Murphy (Eds.), *Science and Football*. London: E. & F.N. Spon.
- Van Leemputte, M., Vandenbergh, K., & Hespel, P. (1999). Shortening of muscle relaxation time after creatine loading. *Journal of Applied Physiology*, 86(3), 840-844.
- Van Loon, L., Oosterlaar, M., Hartgens, F., Hesselink, M., Snow, R., & Wagenmakers, A. (2003). Effects of creatine loading and prolonged creatine supplementation on body composition, fuel selection, sprint and endurance performance in humans. *Clinical Science*, 104, 153-162.
- Vandebuerie, F., Vanden Eynde, B., Vandenbergh, K., & Hespel, P. (1998). Effect of creatine loading on endurance capacity and sprint power in cyclists. *International Journal of Sports Medicine*(19), 490-495.
- Vandenbergh, K., Goris, M., Van Hecke, P., Van Leemputte, M., Vangerven, L., & Hespel, P. (1997). Long-term creatine intake is beneficial to muscle performance during resistance training. *Journal of Applied Physiology*, 83(6), 2055-2063.
- Walker, J. (1979). Creatine: Biosynthesis, regulation, and function. *Advances in Enzymology*, 50, 177-242.
- Weir, J. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research*, 19(1), 231-240.

- Willott, C., M, Y., Leighton, B., Kemp, G., Boehm, E., G, R., et al. (1999). Creatine uptake in isolated soleus muscle: kinetics and dependence on sodium, but not insulin. *Acta Physiologica Scandinavica*, 166, 99-104.
- Wilmore, J., & Costill, D. (1996). *Physiology of Sport and Exercise* (2 ed.). Champaign: Human Kinetics.
- Wisloff, U., Castagna, C., Helgerud, J., & Hoff, J. (2005). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38, 285-288.
- Wisloff, U., Helgerud, J., & Hoff, J. (1998). Strength and endurance of elite soccer players. *Medicine and Science in Sports and Exercise*, 30(3), 462-467.
- Withers, R., Maricic, Z., Wasilewski, S., & Kelly, L. (1982). Match analysis of Australian professional soccer players. *Journal of Human Movement Studies*, 8, 159-176.
- Ziegenfuss, T., Lemon, P., Rogers, M., Ross, R., & Yarasheski, K. (1997). Acute creatine ingestion: effect on muscle volume, anaerobic power, fluid volumes and protein turnover. *Medicine and Science in Sports and Exercise*, 29(S127 (Abstract)).

Appendix 1: Participant Information Sheet

Project Title: **“The acute effects of creatine monohydrate on soccer performance”**

Project Supervisors: **Dr Andrew Kilding & Dr Grant Abt**

Researcher: **Jeremy Williams**

You are invited to participate in a study investigating the acute effects of creatine monohydrate on soccer performance. This study is being undertaken as part of a Masters of Health Science qualification. Participation is completely voluntary and you may withdraw at any stage without giving a reason or being disadvantaged.

What is the purpose of the study?

Athletes involved in repeated bouts of high-intensity training (i.e. soccer training) could benefit from creatine (Cr) supplementation. Cr is a naturally occurring substance that is involved in the generation of energy of muscle contraction. Such increases in Cr levels have been shown to enhance performance by 1) improving PCr and ATP resynthesis, 2) increasing protein synthesis, 3) allowing individuals to train at a higher intensity level and 4) decreasing muscle relaxation time. Anecdotal evidence shows there have been no controlled studies that have documented any significant side effects from Cr supplementation, even during prolonged use (10 to 12 weeks).

Soccer involves repeated high-intensity, intermittent bouts of exercise, which stresses both the muscles metabolic pathways. Potentially therefore, Cr supplementation may be of benefit to soccer players too. There have been no studies to date that have investigated effects of acute Cr ingestion (over seven days) in elite male soccer players. Thus, the purpose of this study is to investigate the effects of Cr on soccer performance using a soccer-specific protocol. The soccer simulation protocol is a performance test that will be conducted over 90 minutes by each athlete replicating the movements of a soccer game. The protocol will consist of forwards running, sprinting, walking, sideways movements, agility aspects (running through agility poles) and accuracy shooting (hitting a given target).

Can I join the study?

Yes, if you are a club level soccer player and have no current injuries or illnesses.

Costs of participating?

You will not incur any monetary costs participating in this study. You will be required to attend two $\text{VO}_{2\text{max}}$ testing sessions (40 minutes) and three testing sessions (90 minutes) over three weeks.

What happens in the study?

This project will be performed over four separate sessions during the hours of 9.00am to 9.00pm. During the first session, you will be given a 10-minute demonstration and a verbal explanation of the soccer-specific protocol followed by a 20-minute warm-up run-through. You will then be required to run the protocol for 45-minutes, have a ten-minute (half-time) break, then perform for another 45 minutes (64 laps in total).

One week later at the same time of day you will repeat the same steps as in session two. After you have completed the soccer-simulation test you will be randomly assigned to either a placebo group or an experimental group. Urine samples will be taken from you before the test.

After seven days supplementation (day 8), you will repeat the soccer-simulation protocol (session four). Urine samples will be taken from you before the test.

What are the benefits?

Since soccer involves repeated high-intensity, intermittent bouts of exercise, which stresses both the aerobic and anaerobic metabolic pathways, Cr supplementation could help improve your soccer performance (less fatigue, more sprints performed, prevent the drop off in performance in the second half). You will also gain measures of your level of fitness for the soccer tests.

What are the discomforts and risks?

The risks involved in this study are minimal. You may experience some mild muscular discomfort and mild fatigue after the testing sessions. You may also experience some mild discomfort/embarrassment when having to urinate into a plastic cup pre and post-test. You will be given a plastic cup and asked to urinate in private in the men's bathroom.

What compensation is available for injury or negligence?

The ACC system, with its limitations, will provide standard cover if participants are injured.

How is my privacy protected?

All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study.

Results

The results of this project will be published in a scientific journal and presented at a national or international conference.

Time To Consider Invitation

You will be given time (7 days) to consider this invitation.

Participant Concerns

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTECH, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Project Supervisor

Dr Andrew Kilding
Division of Sport and Recreation
Auckland University of Technology
Phone 921 9999 ext 7056
andrew.kilding@aut.ac.nz

Principal Investigator

Mr Jeremy Williams
Division of Sport and Recreation
Auckland University of Technology
Phone 921 9999 ext 7346
jeremy.williams@aut.ac.nz

**Approved by the Auckland University of Technology Ethics Committee:
AUTEC Reference number: 05/179**

Appendix 2: Participant Consent Form

Consent to Participation in Research



Title of Project: **The acute effects of creatine monohydrate on soccer performance**

Project Supervisor: **Dr. Andrew Kilding**

Researcher: **Jeremy Williams**

- I have read and understood the information provided about this research project (Information Sheet dated 22 August 2005).
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all my data will be destroyed.
- I agree to take part in this research.
- I wish to receive a copy of the report from the research.
- I do not have any current injuries, or medical conditions that would exclude me from participation.

Participant signature:

Participant name:

Participant Contact Details (if appropriate):

.....

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 19/9/05

AUTEC Reference number 05/179

Appendix 3: Ethics Approval Sheet

MEMORANDUM

To: Andrew Kilding
From: **Madeline Banda** Executive Secretary, AUTECH
Date: 27 September 2005
Subject: Ethics Application Number 05/179
The acute effects of creatine monohydrate on soccer performance.

Dear Andrew

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTECH) at their meeting on 12 September 2005. Your ethics application is now approved for a period of three years until 27 September 2008.

I advise that as part of the ethics approval process, you are required to submit to AUTECH the following:

- A brief annual progress report indicating compliance with the ethical approval given using form EA2, which is available online through <http://www.aut.ac.nz/research/ethics>, including a request for extension of the approval if the project will not be completed by the above expiry date;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/ethics>. This report is to be submitted either when the approval expires on 27 September 2008 or on completion of the project, whichever comes sooner;

You are reminded that, as applicant, you are responsible for ensuring that any research undertaken under this approval is carried out within the parameters approved for your application. Any change to the research outside the parameters of this approval must be submitted to AUTECH for approval before that change is implemented.

Please note that AUTECH grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the Committee and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

A handwritten signature in black ink, appearing to read 'M. Banda', with a stylized flourish at the end.

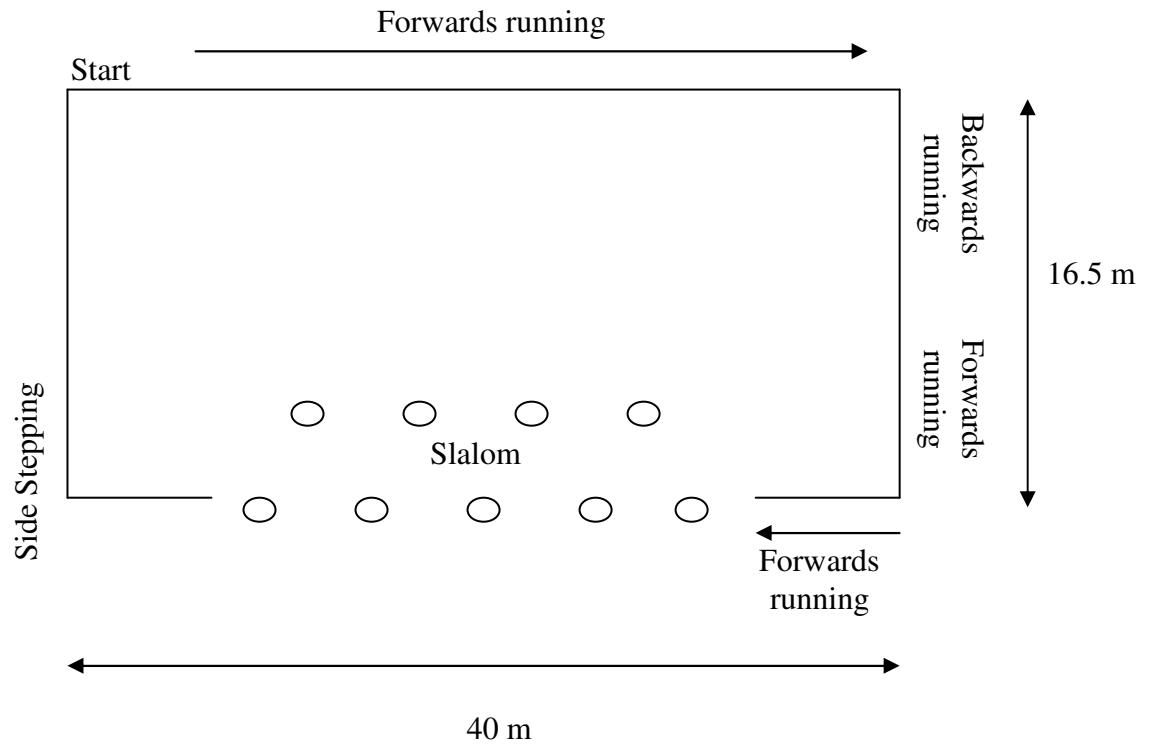
Madeline Banda

Executive Secretary

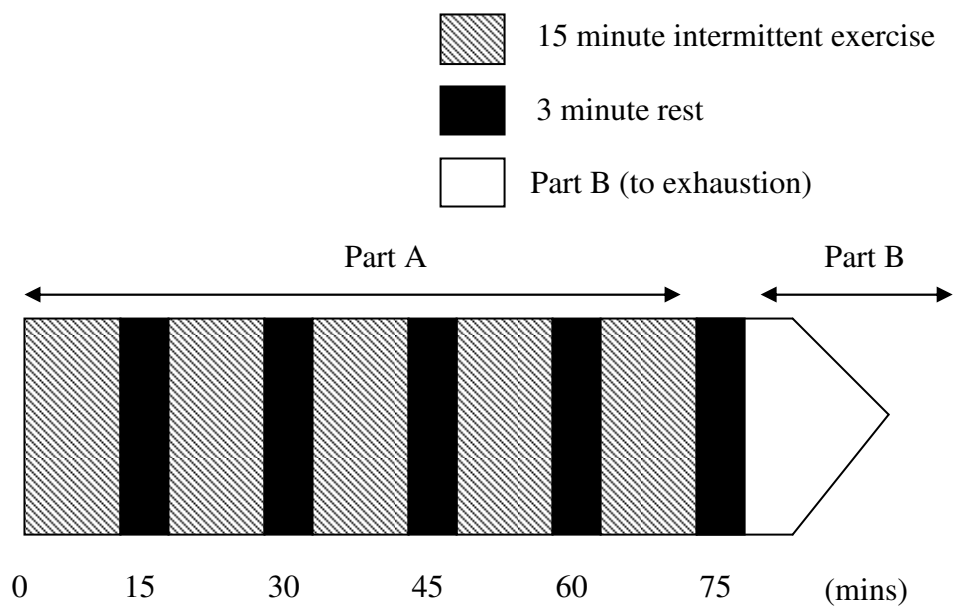
Auckland University of Technology Ethics Committee

Appendix 4: Intermittent Sport Performance Tests

a) Bangsbo's Interval Field Test



b) Loughborough Intermittent Shuttle Test



Appendix 5: Performance tasks at each station of the BEAST

a) Lap 1 (half circuit)

Station	Task	Task Description	Performance measure
1	3m walk	Walk to next station	Time
2	Sprint 12m	12m straight line sprint, slow 23m	
3	Run	75% run 5m	
4	Stop	Stop 8 sec	
5	Walk	Walk 5m	
6	Run	75% run 10m	
7	Decelerate	Decelerate 15m	
8	Stop	Stop 8 sec	
9	Walk	Walk 15m	
10	Run	75% run 10m	
11	Decelerate	Decelerate 5m	
12	Stop	Stop 8 sec	
13	Run	75% run 5m	
14	Slalom	Weave through 3 cones 100%	
15	Stop	Stop 8 sec	
16	Walk	Walk 7m	
17	Run	75% run 28m	
18	Decelerate	Decelerate 10m	
19	Walk	Walk 5m	
20	Backpedal	Jog backwards 7m	

b) Lap 2 (half circuit)

Station	Task	Task Description	Performance measure
1	3m walk	Walk to next station	Time
2	Sprint 20m	20m straight line sprint, slow 15m	
3	Run	75% run 5m	
4	Stop	Stop 8 sec	
5	Walk	Walk 5m	
6	Run	75% run 10m	
7	Decelerate	Decelerate 15m	
8	Stop	Stop 8 sec	
9	Walk	Walk 15m	
10	Run	75% run 10m	
11	Decelerate	Decelerate 5m	
12	Stop	Stop 8 sec	
13	Run	75% run 5m	
14	Slalom	Weave through 3 cones 100%	
15	Stop	Stop 8 sec	
16	Walk	Walk 7m	
17	Run	75% run 28m	
18	Decelerate	Decelerate 10m	
19	Walk	Walk 5m	
20	Backpedal	Jog backwards 7m	Number of goals
21	Accuracy	Shoot at target x6 balls	
22	Jump	x3 Vertical jumps	
23	RPE	Rate of perceived exertion	RPE Scale 6-20

Appendix 6

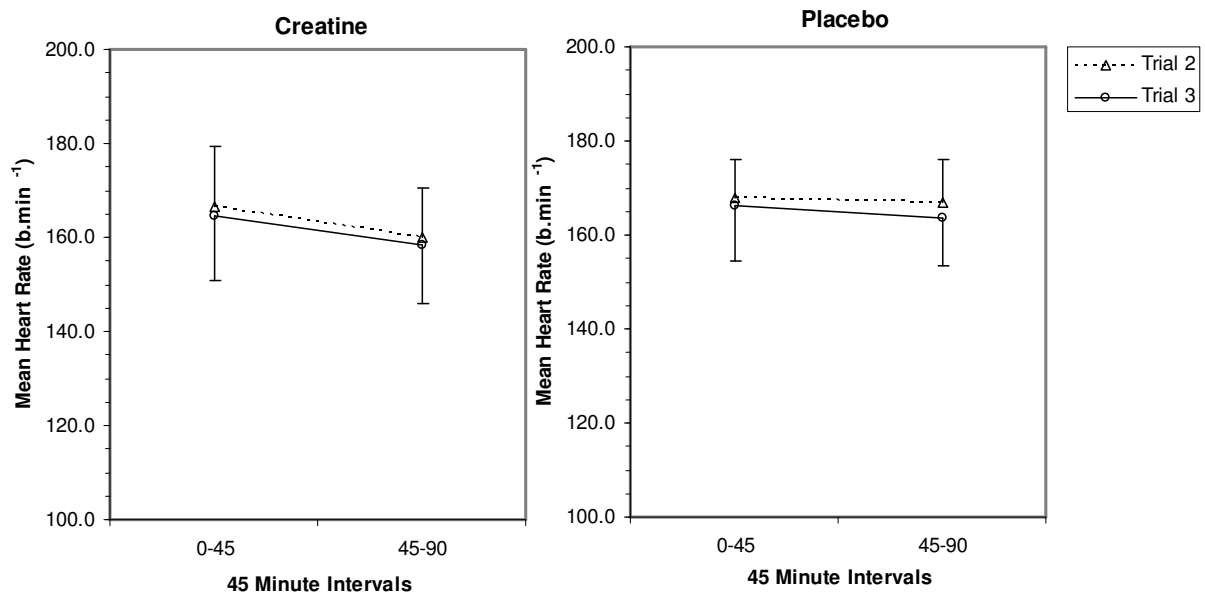


Figure 10: Mean (± 1 SD) HR values each half of the BEAST protocol pre and post-test for both the creatine and placebo groups

Appendix 7

Alternative results for Tables 10 and 11 based on p-values from unequal variance t-test analyses of change scores rather than ANOVA or t-tests that assume equal variances for within-subject error.

Table 16: *Effect of creatine (relative to placebo) on performance measures of the 90 minute BEAST test expressed in Cohen units. Confidence limits, chances that the true effects were substantial and practical assessments of the effects are also shown.*

Performance measure	Cohen ES ¹	± 95% Confidence Limits	Chances that the true effect has substantial ² ...		
			Benefit %	Harm %	Practical Assessment ³
Circuit Time	-0.22	0.55	6	52	Unclear
12m Sprint	-0.53	0.70	2	84	Benefit very unlikely
20m Sprint	-0.39	0.61	3	74	Benefit very unlikely
VJ	-0.13	0.47	8	37	Unclear

Table 17: *Effect of creatine (relative to placebo) on performance measures over the second half (45 min interval) of the BEAST test expressed in Cohen units. Confidence limits, chances that the true effects were substantial and practical assessments of the effects are also shown.*

Performance measure	Cohen ES ¹	± 95% Confidence Limits	Chances that the true effect has substantial ² ...		
			Benefit %	Harm %	Practical Assessment ³
Circuit Time	-0.06	0.43	11	24	Unclear
12m Sprint	0.04	0.48	24	15	Unclear
20m Sprint	0.06	0.73	34	23	Unclear
VJ	-0.15	0.51	7	42	Unclear