NAME: STEPHEN HAYES

UNIVERSITY NUMBER: ST05002458

DEPARTMENT: APPLIED PHYSIOLOGY

INSTITUTION: UNIVERSITY OF WALES INSTITUTE CARDIFF

THE EFFECT OF A PASSIVE OR ACTIVE RECOVERY ON BOWLING SPEED DURING A TEN OVER SPELL

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

APPENDICIES

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF CRICKETING TERMS

Batting – Batting is defending the wicket and scoring runs.

Bowling – Bowling is the process of the bowler delivering the ball to the batsmen.

Crease – The point at which the bowler must release the ball in order to produce a legitimate delivery.

Delivery – The act of bowling the ball.

Field the ball – When the batsmen hits the ball the fielders are required to gather the ball to prevent a boundary being scored. This is called fielding the ball.

Front on action – Technical term for a bowler that looks inside the front arm and backfoot lands straight rather than parallel.

Innings – An innings constitutes one teams opportunity to bat. In the different forms of the game the length of innings will vary.

Over – Six balls delivered by one bowler make up an over

Side on action – is a technical classification for a bowler who looks outside their front arm and the back foot landing is parallel to the crease.

Spell – A spell refers to the number of overs a bowler bowls before being replaced. For example five overs, would be a five over spell

Walking in – The concept of the fielders walking in towards the batsmen when the bowler is running in, in order to pressurise the batsmen and to be prepared to field the ball.

.

LIST OF ABBREVIATIONS

^{o}C	Degrees Celsius
ATP	Adenosine Triphosphate
Bpm^{-1}	Beats per minute
CV	Cardio Vascular
HR	Heart Rate
HR_{max}	Heart Rate Maximum
Km/h^{-1}	Kilometres per hour
$l^{.}h^{-1}$	Litres per hour
LT	Lactate Threshold
$mmol.l^{-1}$	Millimoles per Litre
MAS	Maximal Aerobic Speed
OBLA	Onset of Blood Lactate Accumulation
PA	Power Average
PCr	Phosphocreatine
PO	Power Output
PP	Peak Power
Q	Cardiac Output
SV	Stroke Volume
TTE	Time To Exhaustion
VO_2	Volume of Oxygen Uptake
VO_{2max}	Maximal Oxygen Uptake
WBGT	Wet Bulb Globe Temperature

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Carl Beynon for his great support and guidance throughout my study. His expertise have been invaluable to the study.

I would also like to thank Paul Glazier for the availability and use of equipment, which made the study run smoothly.

ABSTRACT

The current study is an analysis of the effectiveness of a passive, or an active recovery applied to the rest periods when bowling in cricket. The study measured the bowling peak speeds of six healthy male bowlers (20.9 ± 0.96years). Two exercise protocols were prescribed consisting of a ten over spell of bowling (medium to fast paced) under differing recovery periods. One trial used a passive recovery between overs, the other used a three minute active recovery at an intensity of 55%VO_{2max} between overs. Heart rate was measured throughout to maintain active recovery intensity and analyse the heart rate changes during bowling. The results show that there are no significant differences between the speeds in the two trials ($p>.05$). When using a passive recovery the last over is significantly slower than the tenth over ($p<.05$). Whereas when using an active recovery speed is significant quicker between the first over and the fifth, sixth and seventh overs. The fatigue of speed is greater using a passive recovery (12.78 ± 3.63%) compared to active recovery (9.72 ± 1.80%) although not significantly different at the 0.05 level of significance, The key findings of the study are the suggestion that using an active recovery may maintain bowling speed to a greater level than passive recovery, however the results were not significant at the 0.05 level. this is could be linked to the greater amount of oxygen transported to the working muscles aiding the replenishment of Adenosinetriphosphate in three minutes of recovery, however further research is essential to reaffirm this suggestion.

CHAPTER I

INTRODUCTION

1.1 Introduction

Cricket is an intermittent team game which involves short repetitive bouts of intense exercise when batting and bowling. Early research into the physiological demands of cricket suggested that when bowling in test cricket the energy demands were less then that of walking at 6km/h^{-1} and playing tennis, (Fletcher, 1955). The research conducted by Fletcher is questionnable though as he did not directly test the subjects and used previously gathered data so validity and reliability are questionnable. A more accurate classification of cricket by Reilly, Secher, Snell and Williams (1990), states the severity of cricket as moderate with an energy expenditure of 21-33 KJ min^{-1}, also mentioning that it may be an underestimation compared to the elite players. Noakes and Durandt (2000) agree with the early predictions from Fletcher as studies have shown low levels of energy expenditure occur, with the exception of fast bowlers. This study aims to introduce an alternative method to the passive recovery commonly used in bowling and assess the demands on bowling an the influence of recovery mode on bowling speed.

1.2 Forms of the game

At International level cricket is played in three forms, the One Day game, the Test match and the twenty20. The One Day game is where two teams compete in a fifty over per innings match (consult glossary of terms). A Test match consists of two innings per side over the course of five days and the Twenty20 format is a new form of cricket which is a fast paced 20 over per innings game. The physiological demands on bowlers in each format will fluctuate greatly, due to the restrictions placed on the number of overs a bowler can bowl. In a test match there is no limit placed on the bowler whereas in a one day international a ten over limit is enforced and the twenty20 format has a four over limit. The main aim of cricket is to score more runs than the other team. When bowling the aim is to dismiss ten batsmen, then the team is ‘all out’. The two teams change roles and the team who batted first will bowl and prevent the opposition from surpassing their score. It is clear that bowlers are a key member of any cricket side, and anything to aid their performance is of great benefit to a coach and his side.

1.3 Rationale of study area

Once a bowler has completed an over there is on average three minutes and twenty seconds of recovery time before the next over (Fletcher, 1955). During this period the bowler will try to limit the amount of movement during the recovery phase to allow the body to fully recovery without increasing exertion on the physiological systems. Fletcher (1955) suggested when the bowler is fielding they are on average required to field the ball 8.1 times per hour, this shows there is relatively little physiological demands except walking to their fielding position during the rest period.

This study will focus on the activity that the bowler undertakes during this period, and how this impacts upon their bowling speed. Active recovery would involve exercise between overs to maintain blood flow, and increase heart rate (HR). Passive would involve the subjects limiting physical activity to a minimum throughout the recovery period.

The importance of speed in cricket, which supports the relevance and need for a study of this type is summed up by former England Coach Duncan Fletcher.

> *"Cricket is all about speed these days. Fast bowling, fast spin, and fast batting. That means the speed of the ball, bat speed and the speed of revolutions on the ball. That's why I felt that if we had four bowlers bowling over 85mph we had a chance of winning the ashes"*
>
> (Fletcher 2006).

There are many benefits of maintaining bowling speed during a spell. "The ball release speed of a fast bowler in cricket is widely acknowledged as an important characteristic, as it can reduce the decision making and stroke executuion time of the opposing batsmen" (Abernethy, 1981). If a bowler can consistently produce deliveries which are of a high speed they can gain a psychological edge, due to the relentlessness of the bowling attack. If the bowlers speed is in rapid decline the batsmen are able to "line up" the bowler, this means they become more comfortable, have more time for shot selection and can premeditate shots. A batsmen imposing themselves on the bowler in such a way can gain a great psychological advantage and largely puts the batsmen in the acendency.

1.4 Current Research

1.4.1 Heart Rate

The ability to recover quickly is critical if bouts of all out activity are required (Tomlin and Wenger, 2001). Although bowling in cricket is not “all out” in nature, heart rates of 190bpm^{-1} have been recorded. Burnett et al (1995) discovered that bowlers operated at a range of 80.3% of their heart rate max (HR_{max}) in the first over and 84.7% of HR_{max} in the twelth over. The increase in HR was attributed to the greater demand for oxygen in the working muscles as the body fatigues.

1.4.2 Lactate removal

Active recovery has been proven to decrease time to exhaustion (TTE) by decreasing blood lactate concentration. Many studies have been conducted to measure the effectiveness of an active and passive recovery on blood lactate concentration. There is contradictory evidence supporting both modes of recovery and is greatly dependant upon the length and intensity prescribed for both active and passive recovery periods . This can be applied to the recovery of a bowler in cricket as in some cases blood lactate has reached 7.9mmol·L^{-1} (Burnett et al, 1995) in fast bowlers.

1.4.3 Power Output

Active recovery can improve power output (PO) (Spencer, Bishop, Dawson, Goodman and Duffield, 2006) which can benefit the power aspect of bowling. The increased availability of oxygen to the working muscles allows for 90-95% of Adenosine Triphosphate (ATP) replenishment when the recovery period is greater than three minutes. The underlying theory of the active recovery and PO can be applied to the explosive powerful nature of bowling in cricket.

1.5 Practical uses

The results of this study may have practical uses for players and coaches with regards to training regime and on field actions. If the use of an active recovery can enhance the level of performance (speed) then the ideas explored in this study can be applied to amatueur cricketers across the board, and can lead to further investigation in the field of recovery and elite fast bowlers. As there is no research done into recovery of bowlers in cricket and mode of recovery this study is unique and may lend itself to further investigation.

1.6 Conclusion

An extensive literature review shall be conducted in order to determine how the active recovery can be applied to the rest period in bowling and to what extent it may be of benefit to the performer. The research suggests that there may be an improved power performance, which may increase bowling speed. There is also research to suggest that if blood lactate levels rise then there shall be a greater rate lactate removal, however there is contradictory evidence to this.

CHAPTER II

REVIEW OF LITERATURE

The literature review focuses on the physiological processes involved when bowling, and the limiting factors to performance. Two methods of recovery, active and passive, are then introduced as potential ways of maintaining and improving performance, along with their mechanisms and effects.

2.1 Concept of Fast Bowling

Fast bowling in cricket is a highly dynamic skill, which requires the player to generate ball velocities between 35 and 45 m/s^{-1} at the elite level (Burnett *et al*, 1995). During bowling the performer can absorb five times their body weight at the front foot impact (Elliot and Foster, 1984). The process of bowling in cricket consists of a run up, a delivery stride and a follow through. Depending on the type of bowler these will differ. The run up is used to create momentum and gets the bowler to the crease properly to stretch and contract the muscles to produce maximum velocity (Pont, 2006), this could be a thirty meter fast paced run. Mason et al (1989) reported that mean run-up speeds reach a maximum of 6.1^{-1} m/s at 8-16m from the crease during the run up, which is also supported by Elliot and Foster (1985) who found similar results and stated that the speeds generated are similar to that of proffesional Javelin throwers. The second part is the delivery, which is made up of many elements and envolves many muscular contractions. The final part is the follow through and is generally half the length of the run up and is used to gradually decrease the momentum (Pont, 2006). In some instances a bowler could run 45 meters (run up, delivery and follow through), then walk back to the beginning of the run up (45m), and bowl again. This occurs six times in a legitimate over. Burnett *et al* (1995) suggested that 15 overs per hour would be representative of typical first class match conditions so this process can be extremely intense.

2.2 Bowling Speeds during a Spell

It is commonly beliveved that speed and accuracy decline after 6-8 overs of fast bowling (Noakes and Durandt, 2000). Few studies have been conducted in monitoring bowling speeds. Portus *et al* (2000) studied the influence of an eight over bowling spell on performance (speed and accuracy) and technique in fast bowlers. The study discovered that during an 8 over bowling spell the ball speed stayed constant throughout, which also relates to the findings of Burnett *et al (*1995) who discovered that ball velocity ranged from 32.6 m/s^{-1} in the first over to 32.0 m/s^{-1} in the twelth over which suggests the bowlers maintained a constant speed. Both studies used the same passive based recovery proceedure using 'intermittent fielding drills'. The reasons for such results may have been due to the conditions the tests were conducted in. The Portus *et al* (2000) study did not conduct a humidity test however it was stated that the test was conducted throught the winter months, which may have a impact on the results. The Burnett *et al* (1995) study had a wet bulb globe temperature (WBGT) of 28.1 ± 0.8 ^{o}C. This information is important as cricket is played during the warm summer months and studies have shown that sweat rate can dramatically impact on exercise duration in fast bowlers (Gore *et al*, 1993). Sweat rates of 1.5 $l \cdot h^{-1}$ were achieved on humid days, this is comparable to the sweat rates achieved by marathon runners on humid days (Noakes, 1993), and will have a direct impact on spell length and maintaining bowling speed. A study that investigated hypohydration and bowling accuracy (Devlin, Fraser, Barras, and Hawley, 2001) also measured the effects of hypohydration on bowling velocity. There was no significance difference in ball velocity between two trials, one being restricted to a fluid intake (102 ± 0.8 km/h^{-1}) and the other maintaining euhydration (105 ± 8 km/h^{-1}). The methods are disputable however as bowlers completed six overs in one set of conditions (16.0 ± 2.0 ^{o}C), then completed a shuttle run test, followed by one hour of intermittent exercise in a heated room (28 ± $2^{o}C$) and finished by completing the remaining six overs. The methods prescibed are not specific to cricket, however the underlying physiological principles can be applied as during the current study the differences in temperature should not effect the bowling speed.

A study conducted by Elliot and Foster (1984) discovered that the type action (side on or mixed) did not impact on the bowling speed. This was also reinforced in a more recent study by Burnett *et al* (1995) who also reported that bowling velocity did not differ with change in action. This is imporant as it rules out individual technical performance affecting the results. This biomechanical area of bowling has received great deal of attention due to the many possible elements that combine to produce a bowling action. Hanley, Lloyd, and Bissas (2005) reported 5 out of 74 technique parameters are assosciated with ball realease speed, which illustrates the vastness of the research area.

2.3 Recovery from Intermittent Exercise

> "*Repetitive high intensity exercise is performed in many sports. As the final outcome in these sports might be influenced by the athletes ability to perform maximally at a given time, it is of great importance that the athlete recovers from an intense exercise bout as rapidly as possible*".
>
> (Bangsbo and Saltin, 1993, p 49).

During high intensity exercise such as bowling in cricket the HR can increase to 180 and 190 bpm^{-1} (Noakes and Durant, 2000). It is important that the bowler can recover as quickly as possible between overs, as this recovery period will allow the bowler to prolong their maximal level of performance. Bowling in cricket, as previously discussed is intermittent in nature and is physically demanding due to the short burst of energy followed by a longer rest period. During intense exercise such as this, anaerobic energy results from the splitting of endogenous energy rich phosphagens ATP and creatine phosphate (PCr) from glycolysis, which leads to lactate production (Bangsbo and Saltin, 1993). It is important during the recovery period to remove lactate and to replenish stores of ATP, which may not occur during intermittent exercise if the recovery period does not accommodate the process of ATP resynthesis.

2.4 Heart Rate During Exercise

In the majority of studies HR has been recorded during bowling spells. There are many reasons, related to enforcing protocol why it is measured and it can help explain the results achieved during studies. During exercise, the HR combines with stroke volume (SV) to provide an appropriate cardiac output (Q) for the rate of work being performed (Wilmore and Costill, 1994). As the intensity of work increases HR will increase to improve Q. This can be used as a measure of how difficult the task is and an estimate of which energy systems are being used. Gore et al (1993) measured heart rates of twenty cricketers on cool, warm and hot days. The purpose of the study was to measure many variables in simulated cricket matches to identify if players have ample time to rehydrate during cricket. The HR data on the cool day was 121 ± 1 bpm^{-1} (62%HR_{max}) and on the warm day 122 ± 1 bpm^{-1} (63% HR_{max}). The HR values within this study are questionable however as they were logged every minute so did not take into account the intermittent nature of bowling, whereas the study by Burnett *et al* (1995) measured HR every fifteen seconds during the trial, which provides a more accurate account of the demands of bowling. The temperature reading from the study by Burnett *et al* (1995) of 28.1 ± 0.8°C would place the conditions between cool (22.6 ± 0.7 °C) and warm (32.9 ± 0.3 °C) in the Gore *et al* (1993) study. The difference in HR data shows that the Burnett *et al* (1995) study was conducted in comparable cricket weather and gave a more accurate account of the demands of bowling on HR. The HR values can be used in the present study to identify if the bowler is not performing at 100% intensity in the active recovery trial. If the bowler is holding back and not performing to their full extent this will be evident from the HR data being compared to the passive recovery protocol.

2.5 Active Recovery

Active recovery also known as cooling down, or tapering off is described by Katch *et al* (2001) as "where the individual performs submaximal exercise, believing that continued physical activity in some way prevents muscle stiffness and cramps and facilitates overall recovery" (p.169). Numerous studies have been conducted in this field, however the duration of sprints and type and duration of recovery have not been well documented (Spencer *et al*, 2006). The main purpose of an active recovery is to increase the removal of lactate in a muscle. This is important as it can inhibit muscular contractions if concentrations get too high. Foss and Keteyian (1998) suggest that athletes should exercise continuously throughout the recovery process rather than intermittently as this produces a substantial increase in lactate removal, however Dupont, Blondel and Berthoin (2003) argue this makes the recovery "fartlek" in nature and has a negative effect on time to exhaustion (TTE) and creatine synthesis. The optimal level of active recovery intensity has come under much investigation. Belcastro and Bonen (1975) discovered that the optimal rate of lactic removal is between 30% and 45% of VO_{2max} in untrained performers. The optimal lactate removal for trained performers is between 50% and 65% of VO_{2max} as determined by Gisolfi, Robinson and Turrel (1966), whereas McLennon and Skinner (1982) state it should be at 43% of VO_{2max}. It would be reasonable to suggest that the optimal point of lactate removal is a grey area, however the later research provides a more specific point. A study by Swain, Abernathy, Smith, Lee and Bunn (1993) assessed previous methods for using VO_{2max} to calculate the $\%HR_{max}$ at a given intensity. They challenged the protocol used in other studies and the discovered mathematical error. A new system was developed by using linear regression. 81 males (mean 24 yrs) were tested and the principle finding was that healthy young men average 63% of HR_{max} when at 40% of VO_2 consumption. The linear regression line can be used to calculate VO_2 consumption at a given $\%HR_{max}$. The relationship of this information to the current study is that it will enable the current study to set the active recovery period at a given $\%VO_{2max}$ using HR_{max} predictions.

2.5.1 Positives of Active Recovery

The key physiological benefit of the active recovery is lactate removal. There are many contributing studies to support active recovery and its increase in lactate removal. Studies show that active recovery has also been attributed to improving peak power (PP) and average power (PA). The studies conducted in the field of active recovery use a wide range of protocols, which may account for the wide range of conclusions devised, for example the contradictory views on intensity and optimal lactate removal.

There is relatively little research done into PP and PA in relation to blood lactate and recovery. Connolly *et al* (2003) identified that a shorter recovery period that is more specific to performers should be used in more studies as the majority of studies identify with longer recovery times from 5 to 40 minutes. Subjects pedalled on a cycle ergometer all out for 15 seconds and were given either a passive or active recovery. The recovery period lasted for 3 minutes. ATP is 90-95% repleted during this timescale and justifies the work to rest ratio prescribed in the study. The results of the study show a statistical difference in PP and PA in the favour of active recovery. The decrease in power output (PO) from the first trial to the last trial was 10.6% with passive recovery but only 2.9% using an active recovery. This data however could not be credited to lactate removal, as there was no significant difference between the two forms of recovery regarding blood lactate concentration. The results were explained by the increase in blood flow to the muscles and replenishing ATP via PCr resynthesis. Similarly a four-minute period of active recovery enabled an increase in PO when a 30 second sprint was repeated when compared to passive recovery (Bogdanis, Nevill, Lakomy, Graham and Louis, 1996). Bangsbo and Saltin (1993) reported during active recovery there is a significant difference ($P < 0.05$) in blood flow when compared to passive recovery in the legs. The three-minute recovery period used by Connolly *et al* (2003) is similar to the recovery used in cricket and although the mode of activity is completely different the underlying physiological principles could be applied such as ATP replenishment and a maintenance in bowling speed may be observed.

2.5.2 Negatives of Active Recovery

Studies using active recovery have also unearthed negative elements when applied to the practical setting. Dupont *et al* (2003) tested performance in short intermittent runs when using an active and a passive recovery. It was discovered that TTE was greater with passive recovery compared to active recovery. The study combined 15 second runs at 120% of maximal aerobic speed (MAS) with a 15 second active recovery, or passive recovery. The active recovery group ran a distance of 860m shorter than the passive recovery, however their blood lactate reading was 2.5 $mmol \cdot L^{-1}$ less. The reasons for this were attributed to the oxygen used to perform the active recovery preventing the active muscles to reload myoglobin and haemoglobin which is interesting when considering the literature regarding oxygen availability and ATP replenishment improving PP and PA. It was suggested during the passive recovery stage the greater availability of oxygen allowed for more PCr to be restored when compared to the active recovery which is contradictory to other findings. The active recovery protocol turned the exercise into a continuous effort rather then an intermittent exercise. The concept of TTE can be related to cricket as the amount of overs the bowler could perform. The protocol involved in this study is vastly different to the current study as the work to rest ratios are much different, and the subjects worked at a higher percentage HR_{max} (91.3± 2.7%and 92 ± 2.2%) for passive and active recovery respectively. The key findings however could be applied to bowling as using an active recovery a greater decline in speed could occur due to a shorter TTE.

2.6 Passive Recovery

Passive recovery is where inactivity reduces the resting energy requirements and thus frees oxygen for the recovery process (McArdle *et al,* 2001). Passive recovery has been shown to prolong TTE when compared to active recovery as discussed. Passive recovery is used in cricket to allow the HR to decrease gradually and allow the body to use the available oxygen for recovery. This also benefits mental aspects of the game such as concentration.

.

2.7 Blood Lactate Levels during Exercise

Blood lactate does not acumilate at all levels of exercise. Lactate accumilation increases as the percentage of VO_{2max} increases (McArdle *et al,* 2001). Blood lactate increases as exercise becomes more intense and the production exceeds the oxidisation of lactate. At rest blood lactate is approximately 0.5 $mmol \cdot L^{-1}$ to 1.0 $mmol \cdot L^{-1}$ and following exercise it may exceed 10 to 12 $mmol \cdot L^{-1}$ (Foss and Keteyian, 1998). The onset of blood lactate accumilation (OBLA) is a point which researchers have set either at 2.0 $mmol \cdot L^{-1}$ or 4.0 $mmol \cdot L^{-1}$ to represent the point at which blood lactate accumilation begins. The point at which blood lactate levels rise is dependent on the individuals fitness levels. In a fitter individual accumilation occurs at a higher point of their VO_{2max}, however there are many other contributing factors such as muscle fibre type, mitochondrial size and number, and enzyme concentration (Katch *et al,* 2001). An increase in blood lactate can become detrimental to a performer. When the performer exceeds their lactate threshold (LT) which is the point researchers suggest that there is a significant shift towards anaerobic glycolysis (Wilmore and Costill,1994) there is a negative impact on performance. Foss and Keteyian (1998) suggest that the inability of the mitochondrial membrane shuttle to accept H^+ at a pace that is commensurate with production of NADH via glycolysis. This results in the formation of lactic acid in the muscle and the blood, furthermore this leads to an inhibition of contractile performance and leads to premature fatigue. Due to these factors it is important for performers to work at or below the LT to prevent the hinderence to their performance.) The study by Burnett *et al* (1995) was biomechanically based however blood lactate was measured at four stages in a bowling spell. The results from the blood lactate mesurements show that the average resting level was $2.7mmol{\cdot}L^{-1}$ and increased to $4.8mmol{\cdot}L^{-1}$ in the twelth over. Blood lactate measurements did reach $7.9mmol{\cdot}L^{-1}$ as a maximum value in some individuals. The reasons for the low levels of lactate accumilation may be the fitness of the sample group. As they were bowlers from an Australian bowling academy who were match fit. The subjects were not given a set time to complete the overs so they may have taken longer to complete an over giving them more passive recovery time to decrease blood lactate levels. The study also gave the subjects a five minute fluid replenishment break at the end of six overs. In the test match game fluid breaks occur after the first hour. sixteen overs are normally completed by this stage. This inaccurate fluid break may have lead to the blood lactate concentration reducing and effecting the results. This being said in highly trained individuals a short burst of high intensity activity followed by 30 seconds of rest period between deliveries should provide ample break for lactate removal. Even though the average is low for blood lactate during a spell of bowling there still will be a build up of blood lactate which could cause a decrease in speed. As there are no other studies there is no comparison to be made, however if the correct recovery time were applied there may be a greater increase in blood lactate due to less time to oxidise lactate.

2.8 Mode of active recovery used

The literature evaluated thus far has provided insight into the benefits, and negatives of active recovery, and the underlying physiological principles that surround the findings of the authors. One area yet to be assessed is feasibility through mode of activity. Due to the nature of cricket the modes of active recovery reviewed is essential. For example active recovery using a cycle ergometer cannot be used on the cricket field, where as intermittent shuttle runs can.

Table 1. Review of active recovery studies including mode, duration, subject characteristics and summary of results

Author	Mode of active recovery	Subject charecteristics	Duration of recovery	Summary of results
Dupont *et al* (2003)	Subjects ran at 150% of maximal aerobic speed.	12 males subjects. Age 23.6 ± 3.7 yrs. Height 177.4 ± 4.6 cm. Body mass 71.6 ± 8.3 kg.	15 second runs, alternated with 15 seconds active or passive recovery	TTE was Sig shorter with active recovery. Greater distance covered using passive recovery compared to active.
Connolly *et al* (2003)	Cycle ergometer 80rpm with 1kg resistance	7 male cyclists. Age 21.8 ± 3.3yrs. Height 177.3 ± 3.4cm. Body mass 73.0 ± 3.8kgs.	3 minute active recovery period between 6 fifteen second all out sprints	Active recovery sig increases PP and AP compared to passive recovery. No sig difference in blood lactae concentration.

Dodd, Powers, and Brooks (1984)	Subjects cycled at 35%VO2$_{max}$, 65%VO2$_{max}$ and 65%VO2$_{max}$ (7mins) followed by 35%V02$_{max}$ (33mins)	7 trained males Age 29.7 ± 4.9yrs. Height 176.1 ± 6.1cm Body mass 73.2 ± 8kg	Subjects actively recovered for 40mins at varying intensities	Blood lactate disspearance was sig greater with 35% recovery intensity and the 65% and 35% combination than passive recovery and 65% recovery.
Belcastro and Bonen (1975)	Cycle ergometer at 29.7% VO2$_{max}$, 45.3%VO2$_{max}$, 61.8%VO2$_{max}$ and 80.8% VO2$_{max}$.	7 male subjects Age 21.7 ± 2.5yrs, Height 176.1 ± 4.6cm, Body mass 75.6 ± 5.7kg	Subjects actively recovered for 30 mins at varying intensities.	Lactate removal rates were greatest at 29.7% VO2$_{max}$,and 45.3%VO2$_{max}$ sig different to passive recovery. It was also discovered subjects could successfully administer their own active recovery at the correcrintensities.

Bogdanis *et al* (1996)	Cycle ergometer at 40% $VO2_{max}$.	13 male recreational athlete subjects Age 25 ± 3yrs Height 179 ± 7cm. Body mass 78 ± 9kg	Four minute active recovery at one intensity.	Active recovery resulted in a sig greater mean power output when compared to passive recovery. This was attributed to greater blood flow in the muscle
Choi, Cole, Goodpaster, Fink and Costill (1994)	Cycle ergometer at 30 mins 40-50% $VO2_{max.}$	6 college untrained males. Age 22.7 ± 1.5yrs. Height 177.3 ± 3.7cm Body Mass 80.8 ± 5.0kg	30 minute active recovery follwed by 30 minutes seated rest.	Passive recovey results in a significantly greater amount of muscle glycogen resynethesis. Blood lactate removal was greater using an active recovery (P<0.05).

Table 1 shows that the majority of studies are conducted using a cycle ergometer. This effects the quality of relationship in the results when related to cricket. The study conducted by Dupont *et al* (2003) is the only one using running between activity. The work to rest ratio (15 sec work, 15 sec rest) is too short to relate to cricket therefore the TTE is not expected to occur in the current study. The studies by Bogdanis *et al* (1996) and Connolly *et al* (2003) contain recovery periods similar to those used in cricket, but were the only ones discovered within the literature. The mode is again not suitable for cricket, however both experienced increases in PO and PA which may be identified in cricket.

2.9 Hypothesis

The null hypothesis designed are based upon the literature reviewed and previous discoveries made in the research area.

2.9.1. Null Hypothesis

*H*o(1): There are no significant differences in speed when using an active recovery compared to a passive recovery.

*H*o(2): There are no significant differences in speed within a ten over spell when using active recovery.

Ho(3): There are no significant differences in speed within a ten over spell when using a passive recovery.

2.10 Conclusion

Following an extensive review of available literature the most relevant and feasible modes of active recovery are those which are seen to improve the power aspect of cricket. As discovered blood lactate production during bowling is highly unlikely to cause fatigue as the levels achieved. And the mechanisms that may be seen to improve speed will be the availabiltiy of oxygen to the muscles, although this could increase blood lactate levels as suggested by where the oxygen is taken up by active muscles to reload myoglobin and haemoglobin, (Dupont et al, 2003).

CHAPTER III

METHODOLOGY

3.1 Subjects

Six male subjects were chosen from the University of Wales, Institute Cardiff (UWIC) cricket squad. The subjects that were chosen matched the selection criteria.

I. Fit and in good health with no recent injuries or receiving medication
II. A Medium to fast paced bowler (55 - 90+Mph)
III. Must be able work high percentages of HR_{max} for the duration of over an hour
IV. Must be twenty years and over in order to comply with the England Cricket Board (ECB) bowling regulations.

The subject's characteristics are summarised in table 2. Informed consent was acquired in writing from each subject after being informed of the protocol and possible risks of the study.

Table 2. Subject characteristics. (Mean ± *s*),

Age (years)	20.9±0.96
Height (cm)	184.52±11.99
Body Mass (Kg)	80.17±12.48
Predicted HR max (bpm^{-1})	199.1±0.96

3.2 Pilot Study

A pilot study was conducted in advance of the trial to identify if any problems occurred during the passive recovery protocol such as HR recording or bowling speed. Data from the pilot study are summarised in appendix B. There were no problems with the protocol prescribed. The only changed made to the protocol was the units of speed from km/h^{-1} to mph^{-1}. The reason for this as it is more applicable to the cricket setting as speed in International matches in England are measured in mph^{-1}.

3.3 Warm up protocol

The warm up period is essential to all physical performance. Due to the large amount of muscles that are used during bowling a thorough warm up was completed, as it is imperative to avoid the possibility of injury and to maximise performance. The warm up provided a gradual lead up to more vigorous exercise. This process stretched the muscle-tendon unit to allow greater length and less tension when the bowling begins.

The warm up consisted of four minuets progressive jogging. The subjects kept their HR above $120bpm^{-1}$. This was done to ensure that the warm up was progressive and the blood flow to the major muscles would increase, prior to stretching. The subjects then spend four minutes completing stretches both passively and dynamically. Dynamic stretching was encouraged as this type of stretching takes the muscle through the actions that were required during the test. After eight minutes of warm up the subjects completed three practice deliveries to ensure they were fully prepared for the activity.

3.4 Protocol with passive recovery

The testing was conducted in the National Indoor Athletic Centre, Cardiff (NIAC). The humidity and temperature were measured at the beginning of each trial using a weather station (Mobile weather station, Oregon scientific). The protocol used during both passive and active recoveries replicated a real match situation with two bowlers bowling in tandem (alternating), however there was at least a three minute recovery period enforced in the situation of a bowler finishing an over quickly. The bowlers marked out their run ups and checked to make sure that the length was correct to prevent any no-balls (illegitimate) being bowled. The HR monitor was activated start of the first over and the bowler completed a six ball over using a four piece cricket ball (Davidson, India) bowling into a net with a radar gun (StalkerSPORT, Plano) situated behind to measure each ball speed (figure 1). Once the over was complete the second bowler began the study in the same fashion. When the second subject was completing their over the first subject was recovering.

The recovery period involved the subject walking in (see glossary of terms) with the bowler and retrieving the ball from the net. In order to maintain a realistic environment the subjects had to field the ball eight times per hour as the research suggests. This was randomly assigned during the test and involved the administrator rolling a ball out 20 meters into space and the subject retrieving the ball and throwing back at set of stumps. During the test the bowlers were allowed to drink from water bottles at the end of their overs as this is permitted during cricket if a fielder is on the boundary. The subjects were allowed to stretch, but unnecessary high intensity exercise was forbidden such as short sprints. This was to maintain a realistic environment throughout. Once the ten overs were completed the HR monitor was stopped and a cool down was undertaken.

3.5 Protocol with active recovery

The protocol with an active recovery used the same warm up period as was conducted for the passive recovery protocol. Once the subjects had completed the warm up a similar protocol applied. The subjects completed a spell of ten overs while having speed and HR monitored. An active recovery was performed following the over. This was done to increase blood flow to the working muscles, to allow greater resynthesis of ATP and to enhance lactate removal. The use of an online system to calculate VO_2 could not be applied to a cricket setting therefore other means were required to calculate the active recovery intensity. As suggested by Swain *et al* (1993) a percentage of VO_2 can be predicted by using the HR_{max} value. Gisolfi et al (1966) suggest that optimal lactate removal occurs between 50% and 65% of VO_{2max} in trained athletes. A value of 55% HR_{max} was assigned in the current study, this was due to the value not being too excessive to maintain, would increase blood flow in the muscles and if lactate production occurred it would be between optimal levels of removal for trained subjects. Using the method produced by Swain *et al* (1993) 55% of VO_{2max} in healthy fit males is approximately 74% HR_{max}. Using simple calculations 74% HR_{max} was calculated for each bowler, giving a HR value that they must work at during the active recovery. HR_{max} was calculated using an age related prediction HR_{max} = 200 - Age (years) (McArdle *et al,* 2003).

Table 3. %HR_{max} administered during active recovery for different age groups.

Subject	74%HR_{max}
20 years	148 bpm
21 years	147.3 bpm
22 years	146.5 bpm

In order for the subject to maintain this HR short intermittent exercises were conducted between two cones set ten meters apart. The reasons for this were to allow realism, as there is only a limited amount of exercises that could be applied on the cricket field. The subjects prescribed their own active recovery exercises as certain exercises were more suitable for raising the HR and were found more comfortable to perform. The HR monitors worn by the performers were checked by the administrator to ensure the HR was at the desired intensity. Once the rest period was finished the subject immediately bowled the next over. The subjects were authorised to consume water during the study during the recovery period. On completion of the study the subjects conducted a cool down.

3.5.1 Active recovery exercises

During the active recovery short intermittent high intensity exercises were prescribed. The subjects administered their own exercises but were monitored to ensure that no continuous exercises were undertaken. The explanation for the strict protocol was to prevent the nature of the recovery period shifting from intermittent to continuous in nature and affecting the quality of ATP resynthesis.

3.6 Protocol for accessing performance

To access performance a radar gun (StalkerSPORT, Plano) was used to measure bowling speed. The radar gun was attached to a tripod (Velbon DF-40) using a tripod mounting cradle (Stalker, Plano) and placed 3 meters behind a net. The camera was at a height of 160cm and placed directly in line with the angle of delivery (0 degrees) to eliminate any error (Figure.1). The radar gun was set up to record peak speed (mph^{-1}), which is measured within seven inches of the ball leaving the hand. For validity purposes ten percent of the average speed of the first over was calculated. The bowlers speed had to stay within this value to ensure all out effort is achieved.

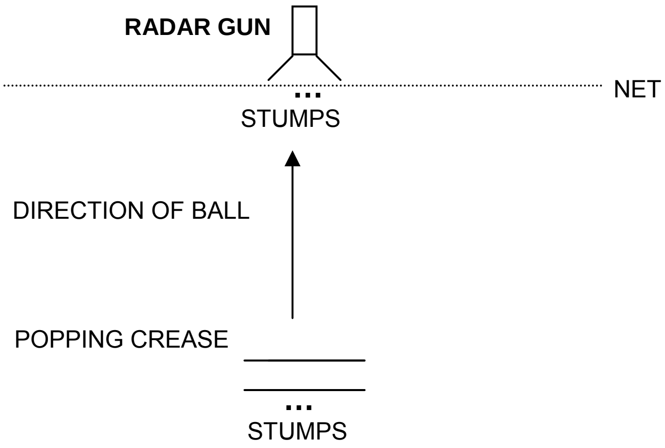

Figure 1. Equipment configuration during both protocols

3.7 Protocol for accessing Physiological measures

3.7.1 Height Protocol

Height was measured using a stadiometer (Holtain Fixed Stadiometer, Holtain LTD). The technique for measuring height adapted from MacDougall, Wenger and Green (1991) was to have the subject stand erect with the heels together, arms hanging naturally by the sides. The heels, buttocks, upper part of back and head are in contact with a vertical wall. The stadiometer was then lowered onto the vertex of the head, as the subject looked ahead and took a deep breath. The height was recorded in centimetres to the nearest tenth of a centimetre.

3.7.2 Body Mass Protocol

Body mass was measured using digital scales (SECA, Hamburg). The subject's mass was recorded with shoes removed and shorts and t-shirt being worn. The mass was measured prior to the experiment in the morning, as this is the most stable time to measure weight (MacDougall et al, 1991). Weight was recorded in Kilograms to the nearest tenth.

3.7.3 Heart Rate Monitoring Protocol

Subjects wore a (Polar S610, Finland) heart rate monitor to record HR in bpm throughout each trial. The HR monitor was set to record at five second intervals, and store the information in a file on the watch. The subjects wore a transmitter belt (Polar WearLink31, Finland) around their chests to transmit the signal to the watch. The file was uploaded from the watch (Polar Infrared USB Interface, Finland) to allow for data analysis.

3.8 Statistical Analysis

Data was collected during the two trials using a laptop computer (Acer Aspire 2002LC, Plymouth) and recorded on spreadsheets using Excel (Microsoft). Descriptive statistics have been used to describe the physiological and speed data collected during the study. The mean accompanied by standard deviation and medians were calculated. The mean gives a measure of central tendency and gives weight to each score according to its relative distance from over scores (Vincent, 1999). The median was calculated as this does not take into account any outlying data and will provide a representation of the typical which best represented the data set. Fatigue index was also calculated by adapting a formula from the Wingate cycle ergometer test (McArdle *et al,* 2001). By adapting the anaerobic fatigue calculation the percentage decline in bowling speed could be identified.

Fatigue Index =

(Highest Peak Speed – Lowest Peak Speed) ÷ Highest Peak Speed x 100

Data was then tested for significant differences using statistics software (SPSS v 16.0). A repeated measures one-way analysis of variance (ANOVA) test was conducted to identify if any significant differences occurred between the spells of bowling. A series of paired *t* tests were conducted to identify if any significant differences occurred during the two trials. The same test was also applied to identify significant differences in the fatigue index of the two trials. A statistical significance of 0.95 was set on all tests.

CHAPTER IV

RESULTS

4.1 Physiological Data

4.1.1 Heart rate Data

Table 4. Heart rate data from the (mean ± Standard deviation) study including conditions of each test

	Passive recovery	Active recovery
Average HR (bpm^{-1})	147.9 ± 17.8	150±12.2
Median (bpm^{-1})	152.1	150.3
% of Maximum HR	73.4%	75.4%
Average Maximum HR	175.5 ± 14.3	174.2 ± 14.01
Average Minimum HR	110.3 ±11.9	120.8 ±13.6
Average Humidity	42 ± 4	44 ± 4.4
Average Temperature(^{o}C)	16.5 ±1.5	16.2 ± 0.4

The HR data in table 4 shows that when using a passive recovery average HR was less than active recovery, however the HR during active recovery was more concentrated about the mean as suggested by the smaller standard deviation, so the active recovery period appears to administered well. The average HR_{max} was greater using passive recovery. This is related to the large standard deviation of average HR, and shows that in short bursts a greater HR was achieved using a passive recovery.

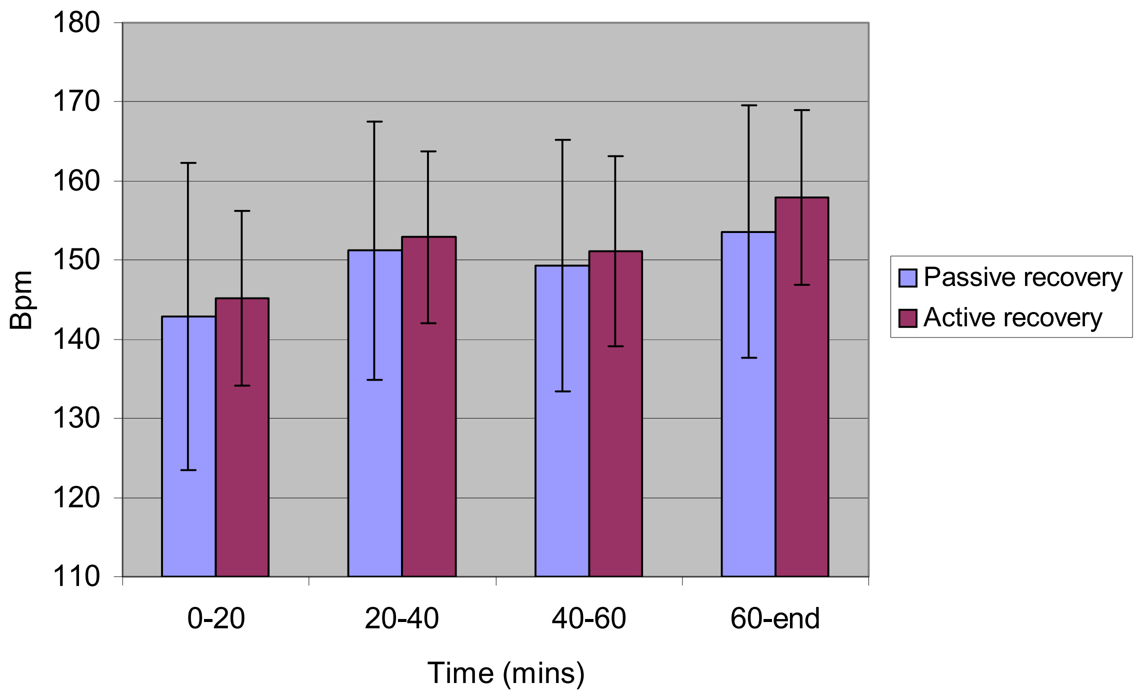

Figure 2. Average heart rate in twenty-minute intervals for passive and active recovery

In figure 2 the HR data was grouped into twenty-minute intervals to identify the changed each twenty minutes, which is approximately three and a half overs. The chart shows that at each interval the average HR was greater for active recovery, and the standard deviation was also less at each stage then that of passive recovery. The average HR decreased for both variables from 20-40mins to 40-60mins then peaked from one hour into the spell until the finish of the spell. During active recovery the mean HR increased from 145.2 ± 11.0bpm^{-1} in the first twenty minutes to 157.9 ± 11.0bpm^{-1} from an hour into the spell to the finish. Whereas when using passive recovery was used the HR increased from 142.9 ± 19.4bpm^{-1} to 153. 6 ± 16.0bpm^{-1} during the same time span.

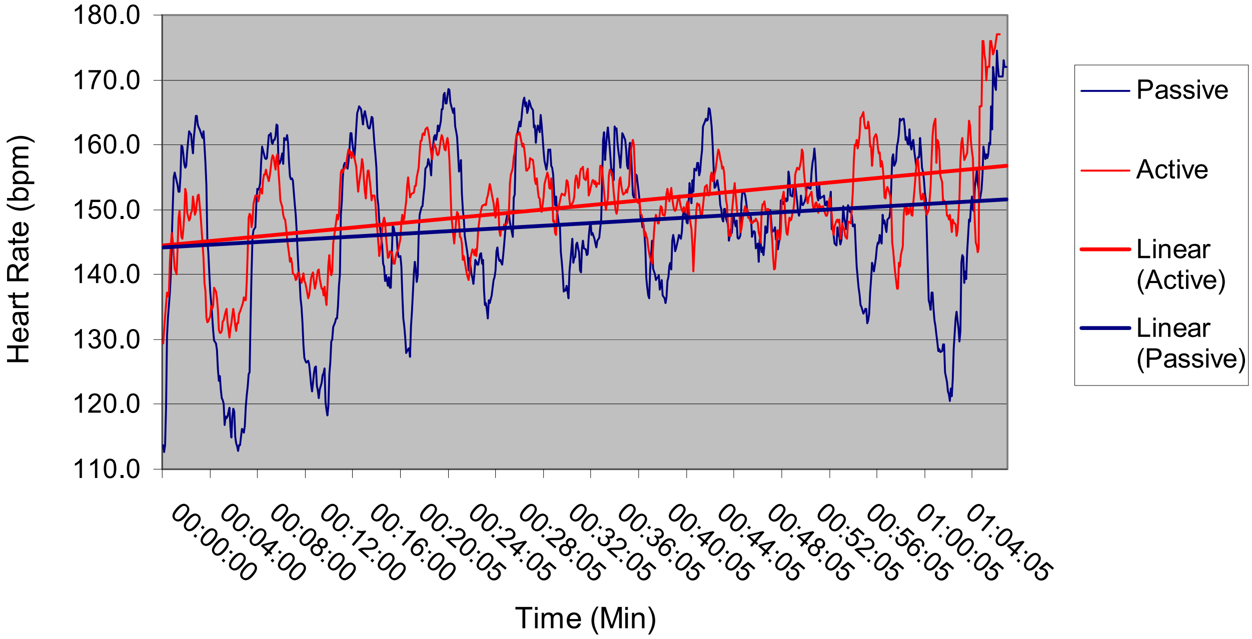

Figure 3. Average heart rate trace for passive and active recovery during the test

A HR trace was compiled containing all of the subject's heart rates over the two trials. The treadline shows that the subjects began at the same relative HR and both progressively increased. The active spell increased HR greater than the passive recovery. The active recovery line is more centred about the mean, thus the low standard deviation. The passive recovery displays more peaks and greater troughs, which suggest a lower HR during recovery and a greater HR during bowling. From figure 3 it can be seen that when using an active recovery the bowlers work at a higher HR during ten overs then using a passive recovery.

4.1.2 Fatigue Index data

Fatigue index was calculated for the each spell of bowling. When using a passive recovery the bowlers fatigue index was 12.78 ± 3.63% whereas when using an active recovery the bowlers fatigue index was only 9.72 ± 1.80%. This result occurred even though when using passive recovery the bowlers worked at a lower percentage of HR_{max} (73.4%) when compared to active recovery (75.4%). A paired *t* test revealed that there is no significant difference in the fatigue index when doing a passive or an active recovery (P >.05).

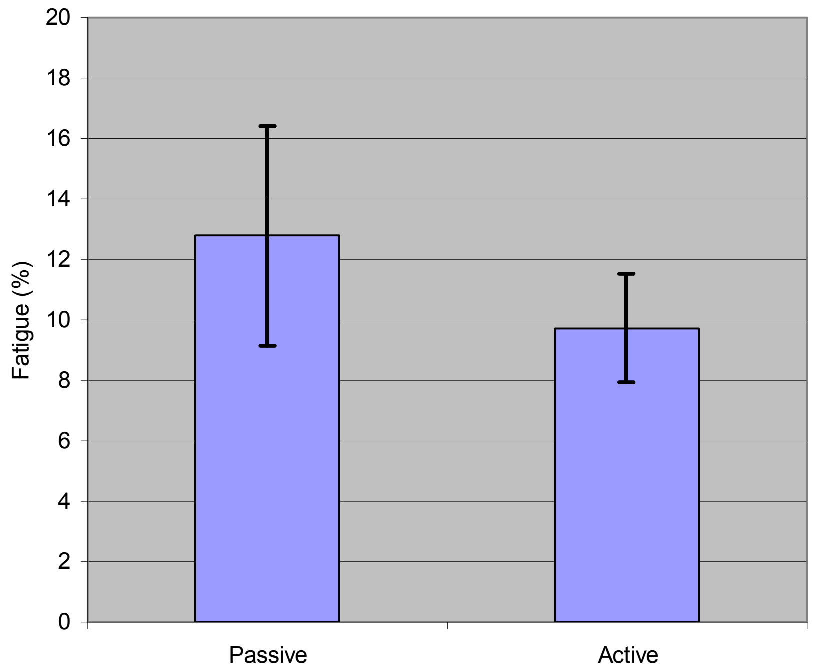

Figure 4. Fatigue index from passive and active recovery during a ten over spell

4.2 Performance data

Box-whisker diagrams can be used to assess if distribution is symmetrical or skewed (Field, 2005). The box-whisker plot for passive recovery is slightly skewed, however the active recovery displays a symmetrical distribution. There is no outlying data, which would be illustrated by a circle outside of the box plot. This shows the similarities in the data collected.

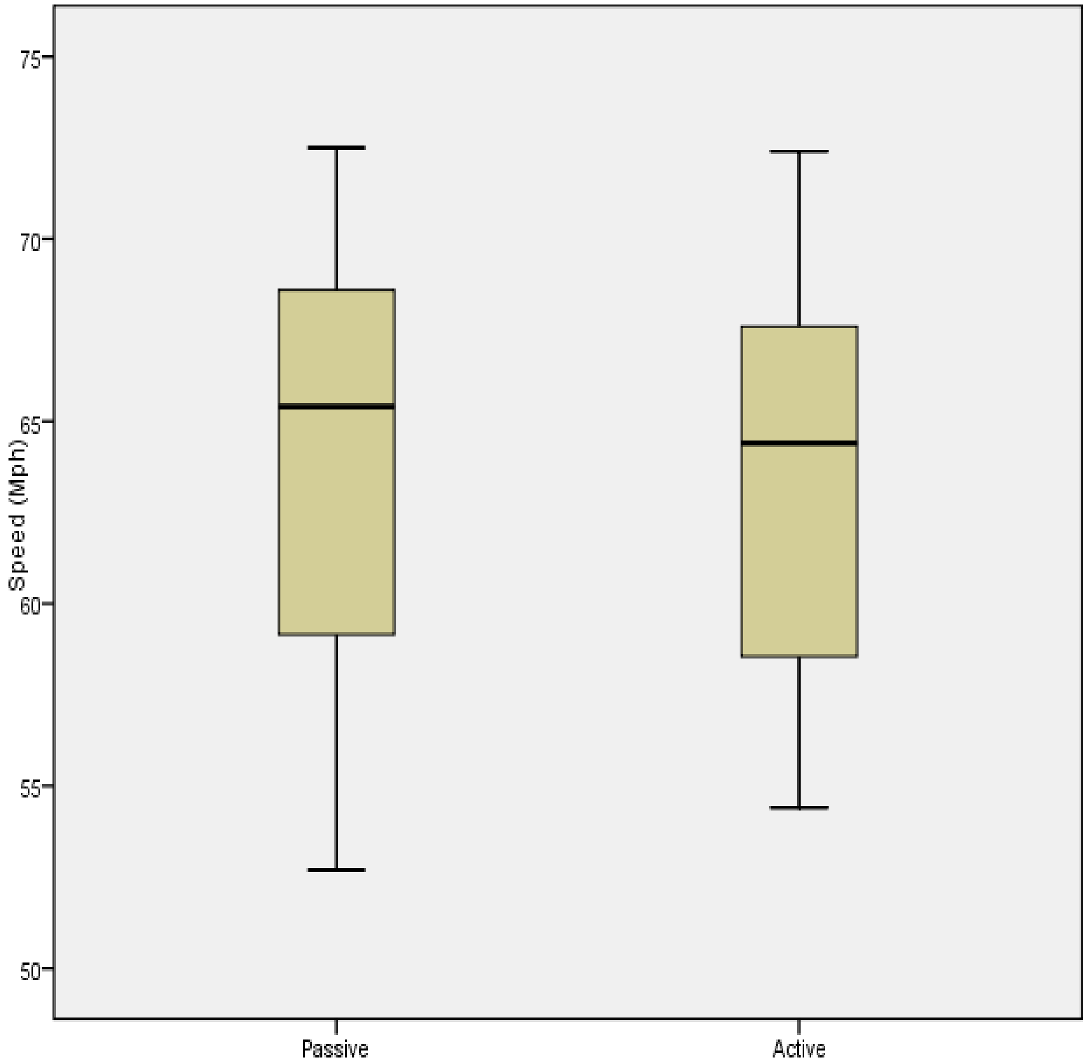

Figure 5. Box-whisker diagram of bowling speeds during the spells

4.2.1 Passive Recovery

During the passive recovery bowling spell the greatest average speed occurred in the second over 65.09 ± 4.99 Mph^{-1}, and slowest speed was located in the tenth over 62.37 ± 5.39 Mph^{-1}, this was at an average HR of 147.9 ± 17.8 bpm^{-1}. As the spell progress the standard deviation of ball speed increases from 4.67 to 4.91 in the seventh and 5.39 in the tenth over, this suggests a greater variability in bowling speed.

4.2.2 Active Recovery

During the active recovery bowling spell the greatest average speed occurred in the fourth over 64.31 ± 5.01 Mph^{-1}, and the slowest average bowling speed was in the first over 62.58 ± 4.30 Mph^{-1}. There was little deviation from the mean during the spell, which suggests consistency in bowling speed throughout the spell as can be seen in figure 6. These speeds were achieved at an average HR of 150 ± 12.2 bpm^{-1}, which is a greater mean HR then using passive recovery.

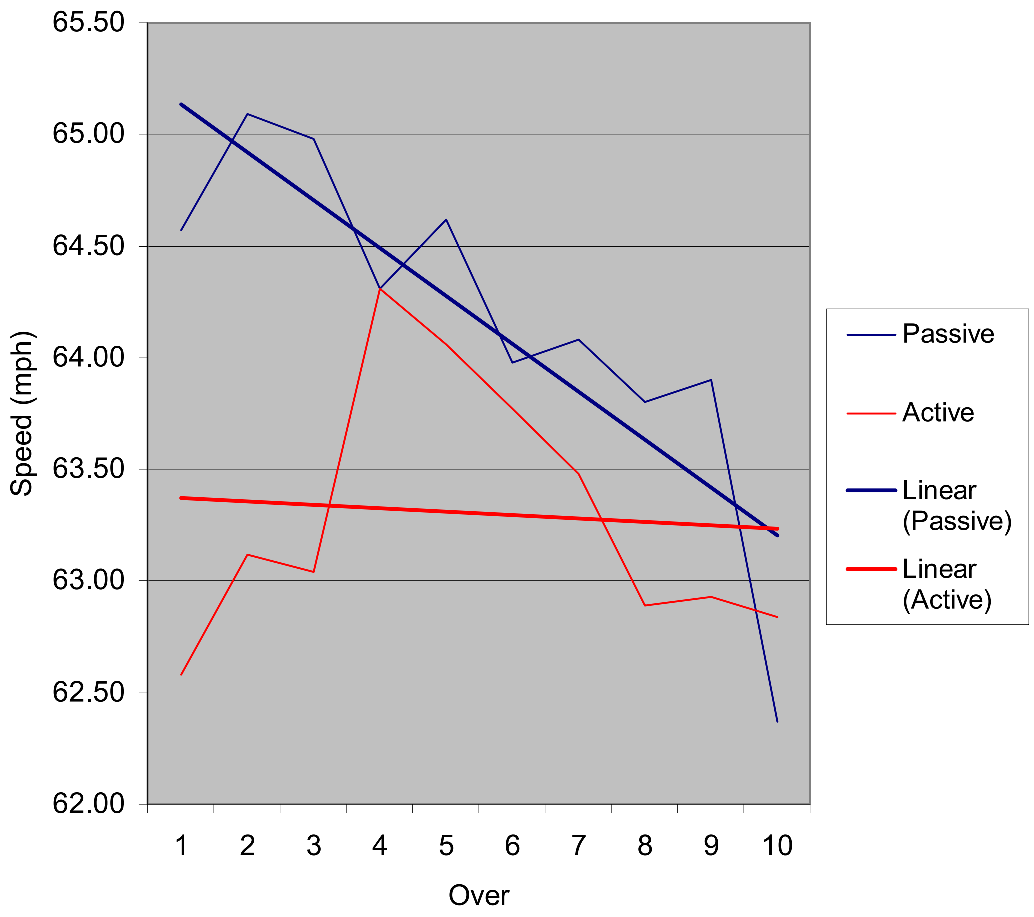

Figure 6. Average bowling speed for passive and active recovery during the test.

Figure 6 displays a trace of the average bowling speeds during the spells. It can be seen that the bowling speed starts much lower when using active recovery however the decline of bowling speed during the spell is much less that using a passive recovery due to the gradient of the line. At the tenth over the two lines have crossed suggesting that speed could be maintained for longer duration using an active recovery.

4.3 Statistical Analysis of Bowling Speeds

Following a repeated measures one-way analysis of variance (ANOVA) there were no significant differences between the two speeds in a spell. However a paired samples *t* test revealed statistically on average subjects bowl faster using a passive recovery (M= 64.2) then using an active recovery (M = 63.3), $t(359) = 5.906$, $p = .000$, $\alpha = .05$. This could be attributed to the active recovery starting at a much slower speed than the passive recovery. Paired *t* tests were conducted to identify if there was a difference between the means of individual overs. Overs were paired and the mean speeds were compared for significant differences.

Table 5. Paired *t* test results showing significant pairings (2 tailed)

Pairing	Significance
Passive over 1 - Passive over 2	.000
Active over 1 – Active over 4	.000
Active over 1 – Active over 5	.000
Active over 1 – Active over 6	.001
Active over 1 – Active over 7	.001
Passive over 1 – Active over 1	.000
Passive over 2 – Active over 2	.000
Passive over 3 – Active over 3	.000
Passive over 8 – Active over 8	.042
Passive over 9 – Active over 9	.034

The table shows that using a passive recovery a significant difference in speed occurs between the first and tenth over. There is no significant difference however between the speed of the first over and the tenth over ($P > .05$) using an active recovery. When an active recovery was used the sixth and seventh overs were significantly faster ($P < .05$) than the first over. From figure 5 it can be seen that when using an active recovery the bowlers started much slower, this has been shown as significantly slower, as has the second and third overs, however the speeds are significantly faster during the eighth and ninth overs using active recovery.

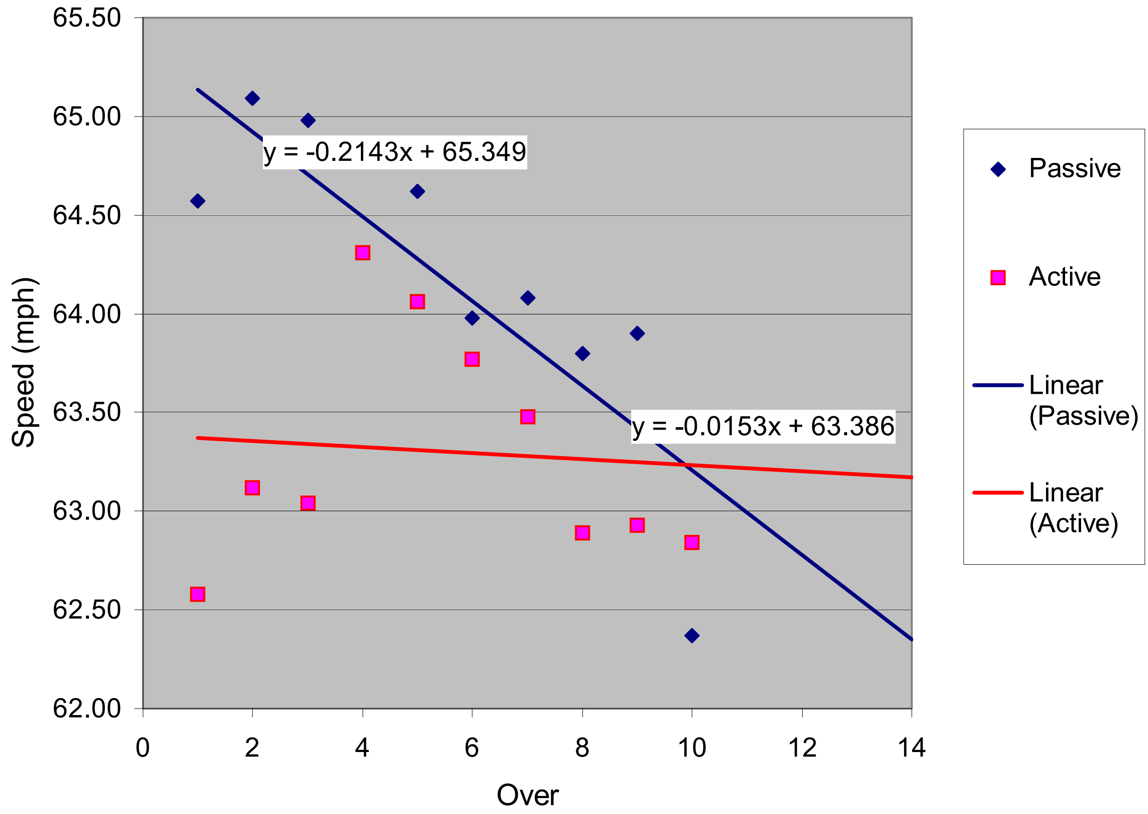

Figure 7. Predicted bowling speeds during a 14 over spell using passive and active recovery.

Figure 7 shows the bowling data of the two studies. The graph displays a forecast of the treadline and a linear regression value. The graph shows that if the study were to continue for four more overs the average bowling speed for bowlers would be less that 62.5mph^{-1} using an active recovery, whereas speed is predicted to be above 63 mph^{-1} for active recovery. These values are only a guide, as they do not take into account the fatiguing physiological elements of bowling. The linear regression line shows that for passive recovery the bowler's speed declines by 0.21 mph^{-1} each over, whereas speed declines by 0.015 mph^{-1} each over for active recovery.

CHAPTER V

DISCUSSION

5.1 Physiological Responses to 10 Overs of Bowling

The HR data was collected during the two procedures to evaluate the physiological demands associated with bowling under two contrasting recovery conditions. There are many contributing factors which will greatly affect the HR readings recorded such as temperature and humidity. The heart rates were primarily calculated to ensure that the recovery periods were both active and passive in nature and the HR was maintained to the desired percentage of predicted VO_{2max} during the active recovery period, which represented an increase in blood flow.

5.1.1 Heart rate responses using passive recovery

In previous studies conducted by Burnett *et al* (1995) bowlers worked at 80.3% to 84.7% of their HR_{max} during twelve overs of bowling in a simulated match situation. The results in the current study show that the subjects worked at a lower intensity of 73.4% of their HR_{max} during ten overs of bowling. The findings of the current study are more supportive of previous work by Devlin *et al* (2001), whose subjects displayed an average HR of 67.0% HR_{max} throughout a six over spell, and are similar to that of Gore *et al* (1993) where bowlers worked at 62.0% HR_{max} and 63.0% HR_{max} on cool and warm days respectively. The HR results from this study fit between the findings of previous studies, however as discussed many contributing factors justify the wide range of findings such as conditions. When compared to

Burnett *et al* (1995) the HR data is of stark contrast. A suitable explanation is the difference in conditions of the two studies. The temperature in the Burnett *et al* (1995) study was (28.1 ± 0.8 ^{o}C) compared to (16.5 ± 1.5 ^{o}C), and (16.2 ± 0.4 ^{o}C) for passive and active respectively in the current study. The greater temperature throughout the spell could affect cardiovascular (CV) function as a large part of Q must be shared by transporting blood to the skin, rather than the working muscles (Wilmore and Costill, 1994). As Q needs to be maintained, and SV decreases due to the redistribution of blood lowering the end-diastolic volume (Wilmore and Costill, 1994), therefore HR must increase to maintain Q, a process known as cardiovascular drift.

When using passive recovery the HR fell below 120bpm in the first two overs and below 130bpm in the third during recovery between overs. This did not occur at any stage during the active recovery trial, which demonstrates the active recovery target HR was attained. This produced the lower mean HR value for passive recovery however it is interesting to note the passive recovery trial achieved a higher HR_{peak}. This could be attributed to the limited amount of exercise allowing the HR to drop more so than using active recovery. When the bowler begins the next over the heart must work harder to increase the blood flow to the active muscles, to allow replenishment of ATP and forceful muscular contractions.

5.1.2 Heart rate responses using active recovery

There is no literature in the area of active recovery and bowling speeds therefore no comparative analysis between similar studies can be made. The data can be compared to that of the passive recovery study. The mean HR for active recovery (150 ± 12.2 bpm^{-1}) is greater than that of passive recovery (147.9 ± 17.8 bpm^{-1}). The standard deviation is also much smaller, due to the HR being maintained consistently close to the mean throughout the spell. The maximum and minimum HR values from the two studies also show that when working actively the HR was maintained consistently close to the mean, whereas passive recovery was more spread, as can be seen in figure 3. This clarifies that throughout the active trial the blood flow was maintained to a greater extent then that of the passive recovery. The maximum HR value achieved throughout the active recovery (174.2 ± 14.0 bpm^{-1}) trial was less then that of the passive recovery (175.5 ± 14.3 bpm^{-1}), which was not expected as the subjects were working the cardio vascular (CV) system for a longer duration. The HR data is a measure of how hard the CV system is working. When the bowler uses an active recovery they are working the CV system harder due to the greater mean HR. This may have implications on the mental aspects of bowling such as concentration and motivation, and will physiologically have an impact on homeostasis within the bowler, such as water loss through increased sweating. McArdle *et al* (2001) suggest that sweat loss places a greater strain on circulatory function and impairs exercise capacity. If an active recovery is used the increased demands may increase water loss and effect key physiological elements such as dehydration, plasma volume (decrease), increase chance of heat injury (in hot conditions) and TTE.

5.1.3 Fatigue Index

The fatigue index was calculated to identify the fatigue of the bowler during the spell. In previous studies in cricket no measurement of this kind has been made, so there is no data to compare the findings to. When using a passive recovery the fatigue index was 12.78 ± 3.63% over ten overs, whereas when using active recovery a fatigue index of 9.72 ± 1.80% occurred. These results do suggest active recovery may possibly reduce fatigue index, however the result was not statistically significant at the 0.05 level of significance. When the HR data is taken into consideration the findings become more interesting. When the bowlers worked at a higher percentage of their HR_{max} (active recovery) their fatigue was less when compared to the passive protocol. These results may well be a result of the concept that increased blood flow allows PCr stores to be replenished after three minutes, thus allowing the subject to repeat muscular contractions for a greater duration. The results of this study are similar to the results gathered by Connolly *et al* (2003) in which active recovery had a greater effect on the decrease in PO when compared to passive recovery. Although the mode of activity was much different from the current study the underlying principles may be applied and provide an explanation for the current results. The PCr replenishment allows the power to be maintained, which can be related to bowling where the more power generated at the point of release the greater the ball velocity will be. An argument for this finding is the speed of the first over. Due to the bowlers not reaching the same speeds in both protocols for the first overs the fatigue index may be misleading. If the active recovery trial had achieved the same speed in the first over as passive recovery the fatigue index may have been less as they may have had a similar decline of speed. This may affect the confidence in the statistic, as this is the first study it has been applied to. This considered, the statistic appears to support the literature for maintenance of PA and TTE.

5.2 Influence of Conditions on Results

As established humidity and temperature can play a major role in the performance of bowlers in cricket. If humidity levels are high little or no evaporation of sweat from the skin can occur due to the air being saturated with water. Consequently body heat can rise, leading to more blood being pumped to skin in an attempt to decrease body temperature, and thus increases HR. The conditions on the days of the two studies were very similar in both humidity (42 ± 4% and 44 ± 4.4%) and temperature (16.5 ±1.5 ^{o}C and 16.2 ± 0.4 ^{o}C) for passive and active respectively. The small standard deviation suggests that throughout the studies there was little range in conditions and therefore should not pose any difference between the two trials.

5.3 Comparisons of bowling speeds

There were no significant differences in bowling speeds when using a passive recovery compared to an active recovery. This means the null hypothesis *H*o(1) can be accepted. The significantly slower first over using active recovery may have affected the quality of results.

5.4 Bowling speeds using passive recovery

The bowling speed throughout the passive recovery spell declined gradually as was expected. There was a significant difference between the speed of the first over and the tenth over ($P < 0.05$), which means the null hypotheses *H*o(3) can be rejected. Noakes and Durandt (2000) suggested that a decline in speed occurs after six to eight overs, however no significant decline in speed occurred after six to eight overs during this protocol. Findings from studies by Burnett *et al* (1995) and Portus *et al* (2000) show that bowling speed remained constant through twelve and eight overs respectively when using a similar recovery protocol. A linear regression line (Figure 7) shows that each over bowling speed declines by 0.21 mph^{-1}. Using this calculation a prediction can be made on the decline of speed in bowlers. For example if a bowler is bowling at 80mph in the first over by the tenth overs their speed may decline to 77.9mph. (Decline in speed = peak speed – 0.21 x overs). There are many limitations to this however such as individual differences, conditions and game situation.

The passive recovery protocol produced the greatest speeds. When related to the HR data, the results suggest that when bowlers work at a lower percentage of HRmax their speeds are quicker during ten overs, however their fatigue index is greater. The physiological reasoning for these results could be attributed to an increase in SV, which would decrease HR do maintain Q. A more suitable suggestion however relates to the technical side of bowling. Hanley *et al* (2003) suggested that 5 out of 74 technique parameters effect the ball release speed. This presents a difficulty in control and may explain why slight differences occur, for example if the angle of the front knee were significantly different over the two trials the bowling speeds would be greatly affected.

5.5 Bowling speeds using active recovery

When using an active recovery the bowling speed data is of vast contrast to the passive recovery spell. The mean speed for the first over (62.58 ± 4.30 mph^{-1}) was significantly lower than the forth, fifth, sixth and seventh overs respectively in the same spell, which means *H*o(2) can be rejected. It is reasonable to suggest that psychological reasoning such as the subject restraining themselves due to the physiological demands of the protocol may affect the quality of the first over. The same warm up was conducted for both trials therefore subjects were similarly prepared for each of the protocols. It would be fair to apply the same reasoning from Hanley *et al* (2003) as previously discussed regarding technical parameters. The significantly slower first over greatly affected the average speed of the active recovery protocol, which may affect the wider use of the study. Other factors that may contribute to the significantly slower first over may be factors that were not measured such as the fluid and food consumption prior to the trials.

The main discovery from the study was the rate of decline in speed when using an active recovery. If the same analogy of a bowler starting at 80mph and bowling fifteen overs is applied to active recovery their speed shall decline to 79.85mph. Again as mentioned this is a rough guideline based on linear regression and too flaccid to firmly state the outcome due to the slow first over and individual differences. When the subjects were working at a higher percentage of HR their speeds were slower. This would illustrate that as the demands on the body increase the ability to reproduce forceful muscular contractions is more challenged and may account for the slower speeds achieved.

5.6 Suggestions for Differences

There are many interesting findings within the current study. The method focused on achieving an active recovery of 55% Vo_{2max}. A key finding of the study was the rate of decline in speed throughout the active recovery trial. It is possible that the three minutes of increased blood flow compared to passive recovery (due to increased HR) provided ample time to replenish stores of ATP as suggested by Connolly *et al* (2003). It is important to consider the physiological mechanisms when passively recovering. As the demands on the body were less during the recovery period the oxygen that would be used producing active recovery could be used to reload myoglobin and haemoglobin. Myoglobin stores oxygen and releases it to mitochondria during the transition of rest to aerobic exercise (Wilmore and Costill, 1994). During the active recovery the process of reloading myoglobin may have been restricted. The opportunity to reload myoglobin would provide the muscles with oxygen during the lag between the beginning of the over and the CV delivery of oxygen.

Lactate removal may also have aided the ability of the bowler to maintain bowling speed during the active recovery. This could be due to lactate being taken up by the skeletal muscle and metabolised via re-conversion of pyruvate and entry into the krebs cycle (Brookes, 1986). If the lactate build up were high enough for this process to have an effect, (blood lactate levels of as levels of $7.9 mmol \cdot L^{-1}$ have been achieved, Burnett *et al,* 1995) then the improved ability to reproduce the forceful muscular contractions in bowling may help the maintenance of speed. The active recovery protocol was designed as aforementioned to work at 55%VO_{2max}. This was to comply with previous research on optimal levels of lactate removal.

The key findings of the study are the suggestion that using an active recovery may maintain bowling speed to a greater level than passive recovery, however the results were not significant at the 0.05 level. When bowlers bowl faster they fatigue to greater level as suggested by fatigue index, however it is also suggested that when using an active recovery bowlers fatigue less then using a passive recovery although bowlers worked at a higher HR for a longer duration.

When using an active recovery the first over of the spell is significantly slower ($p>0.05$) than using passive recovery, but speed is significantly greater when comparing the first over with the fifth, sixth and seventh overs, which does not occur during passive recovery. So therefore bowlers become quicker in the fifth, sixth and seventh overs of a ten over spell using an active recovery.

CHAPTER VI

CONCLUSION

6.1 Introduction

The initial purpose of the current study was to identify the effect of an active or a passive recovery on bowling speed. The study has discovered that there are no significant differences in bowling speed when using the two recoveries. There are significant differences within bowling spells however. Speed is significantly slower when using passive recovery from the first and tenth over, whereas using an active recovery speed becomes significantly quicker during the fifth, sixth and seventh overs. Linear regression shows that speed decreases at a greater rate using passive recovery then that of active recovery, which coincides with a greater fatigue index for passive recovery. Therefore, in summary the differing recovery periods produce differing results, a passive recovery allowed bowlers to attain a greater peak speed, but an active recovery allowed bowlers to fatigue at a slower rate, and maintain their speed to a greater extent during a spell.

6.2 Implications for coaches and players

The main concerns with the methods in a study of this nature was feasibility. Due to the nature of current research regarding active recovery and the methods used a research design that considered the forms and rules of the game was required, and achieved by the simple protocol used. The results as discussed have implications for coaches although there is an evident need for future research. The use of an active recovery will be beneficial to bowlers who work at a very high intensity (%VO_{2max}) for the duration of the delivery. This is due to the greater demands placed on the CV system and more forceful muscular contractions. This can cause an increase in blood lactate, but as the literature suggests intermittent active recovery can increase the removal of lactic acid. These physiological processes will enable the bowler to reproduce fast deliveries due to the removal of lactic acid. The results also suggest a bowler can apply an active recovery to maintain bowling speed, although the speed will be slower in doing so for the first ten overs. This can be of great use to a coach as in games where fast bowlers are required to bowl for a long spell (over ten overs) their speed will be quicker in the latter overs and more consistent then if they were to use a passive recovery, this relates to the aforesaid points on psychological advantage and reaction time for the batsmen by Abernethy (1985).

6.3 Limitations

The current study has produced a range of descriptive and statistical results that can have implications for players and coaches as discussed. There is a great need for more physiological variables to be considered. The feasibility as mentioned was the underlying theme of the active recovery, therefore online methods of calculating VO_2 and RER were not feasible as this cannot be used on the cricket field. Another limitation of the study was the lack of VO_2 test, this would enable the subject to work at more precise value of VO_{2max} but again this would include an online method of recording data, which cannot be achieved on the cricket field. The method aimed to raise the HR as a measure of blood flow. A catheter could be used to accurately measure blood flow, however this procedure is extremely invasive, but would give an accurate reading if an increase in blood flow occurred. A final variable that could have been measured was blood lactate, although from the review of literature it was evident that the build up of blood lactate is generally low so should not pose an immediate detriment to bowling speed. A consideration must be made to the temporal scale of the study. The study was conducted in the winter months, the off-season in cricket. Although the subjects were well trained they lacked match practice. This lack of bowler specific fitness may affect the speeds achieved throughout the study. The final limitation to the study relates to research by Hanley *et al* (2003) whereby 5 out of 74 technical variables can impact ball release speed. This does not take into account physiological differences and environmental differences. This demonstrates that much greater control is necessary in a study of this nature as one element may greatly affect the results. A limitation within the protocol was the order of recovery. All subjects completed the passive recovery first and the active recovery second. This could have a psychological affect, as the subjects may not have worked at 100% intensity the second time around. A more appropriate method where one half the subjects did an order of passive then active recovery and the other half did it in order of active then passive may generate a greater quality in results.

6.4 Future research recommendations

The current study has demonstrated there is a need for future research within this area, and due to the limitations there are many areas that future researchers can focus upon. The subject size is certainly an area that can be improved upon and it is clearly evident that a larger sample size is necessary in order to achieve a more accurate representation of the cricketing population. Future research should also be more specific to cater for different speed of bowlers. Bowlers vary in pace, and an effort should be made to group bowlers, so that differences between a cohort can be more specifically scrutinised.

Future research can also aim to measure more physiological variables under differing conditions. An example would be to assess active recovery in varying climates, as this may greatly effect the application of the active recovery, and identifying blood lactate concentrations and VO_2 values. Future researchers could use video analysis in order to relate the specific HR reading with each delivery. The data could then lend itself to further investigation such as the HR at different stages of the over, this type of method as seen in the study by Burnett *et al* (2005).

REFERENCES

Abernethy, B. (1981). Mechanisms of skill in cricket batting. *Australian Journal of Sports Medicine,* **13**, 3-10, cited in, Salter, C. W., Sinclair. and Portus, M. R. (2007). The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches, *Journal of Sport Sciences,* 25,**11**, 1279–1285.

Bangsbo, J. and Saltin, B. (1993). Recovery of muscle from exercise – its importance for subsequent performance. Cited in, MacLoeod, D.A.B., Maughan, J.R., Williams, C., Madeley, C.R., Sharp, J.C.M. and Nutton, R.W. (1993). *Intermittent high intensity exercise,* E & FN SPON, London.

Bartlett, R.M., Stockill, B.C., Elliot, B.C., and Burnett, A.F. (1996). The biomechanics of fast bowling in men's cricket: A Review, *Journal of Sports Sciences*, 1996, **14**, 403-424.

Belcastro, A. N. and Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled recovery exercise. *Journal of Applied Physiology*, 39, **6**, 932-936.

Bogdanis, G. C., Nevill, M. E., Lakonmy, H. K. A., Graham, C. M. and Louis, G. (1996). Effects of active recovery on power output during repeated maximal sprint cycling. *European Journal of Applied Physiology,* 74, **5**, 461-469.

Burnett, A.F., Elliot, B.C. and Marshall, R.N. (1995). The effect of a 12-over spell on fast bowling technique in cricket. *Journal of Sport Sciences,* **13**, 329-341.

Choi, D., Cole, K. J., Goodpaster, B. H., Fink, W. J. and Costill, D. L. (1994). Effect of passive and active recovery on the resynthesis of muscle glycogen. *Medicine Science of Sports Exercise*. 26, **8**, 992-996.

Connolly, D. A. J., Brennan, K. M. and Lauzon, C. D. (2003). Effects of active versus passive recovery on power output during repeated bouts if short term, high intensity exercise. *Journal of Sports Science and Medicine*, **2**, 47-51.

Devlin, L.H., Fraser, S.F., Barras, N.G. and Hawley, J.A. (2001). Moderate levels of hypohydration impairs bowling but not bowling velocity in skilled cricket players. *Journal of Science and Medicine on Sport.* 4, **2**, 179-187.

Dodd, S., Powers, S.K., Callender, T. and Brookes, E. (1984). Blood lactate disappearance at various intensities of recovery exercise. *Journal of Applied Physiology,* 57, **5**, 1462-1465.

Dupont, G., Blondel, N. and Berthoin, S. (2003). Performance for short intermittent runs: active vs. passive recovery. *European Journal of Applied Physiology*, 89, 548 – 554.

Elliot, B.C., and Foster, D.H. (1984). A biomechanical analysis of the front-on and side-on fast bowling techniques, *Journal of human movement Studies,* **10**, 83-94.

Field, A. (2004). *Discovering statistics using SPSS* (2nd edition), SAGE, London.

Fletcher, D. (2006). 'no title', cited in, Pont, I. (2006). *The fast bowler's bible*, Crowood press, Wiltshire.

Fletcher, J. G. (1955). Calories and cricket. *Lancet*, **1**, 1165-1166.cited in Noakes, T. D. and Durandt, J. J. (2000). Physiological requirements of cricket, *Journal of Sport Sciences,* 18, (12), 919-929.

Foss, M.L. and Keteyian, S.J. (1998). *Physiological Basis for Exercise and Sport* (6th edition), WCB McGraw-Hill, Boston.

Foster, D.H. and Elliott, B.C. (1985). Fast bowling: An impact sport. A profile of D.K. Lillee. *Sports Coach*, **9**, 3-7. cited in, Bartlett, R.M. (1996). The biomechanics of fast bowling in men's cricket: A Review, *Journal of Sports Sciences*, 1996, **14**, 403-424.

Gisolfi, C., Robinson, S. and Turrell, E.S. (1966). Effects of aerobic work performed during recovery from exhausting work. *Journal of Applied Physiology*, 21, **6**, 1767 – 1772.

Gore, C.J., Bourdon, P.C., Woolford, S.M. and Pederson, D.G. (1993). Involuntary dehydration during cricket. *International journal of sports medicine,* **14**, 387-395.

MacDougall, J. D., Wenger, H. A. and Green, H. J. (1991). *Physiological testing of the high performance Athlete (second edition)*. Human Kinetics, Leeds.

Mason, B.R., Weissensteiner, J.R. and Spence, P.R. (1989). Development of a model for fast bowling in cricket. *Excel,* cited in, Portus, M.R., Sinclair, P.J., Burke, S.T., Moore, D.J.A. and Farhart, P.J. (2000). Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sport Sciences.* 18, **12**, 999-1011.

McArdle, W.D., Katch, F.I. and Katch, V.I. (2001). *Exercise physiology: Energy, Nutrition and Human Performance* (5th Edition) Lippincott, Williams and Wilkins, Baltimore

Noakes, T.D. (1993). Fluid replacement during exercise. *Exercise and Sports Science Reviews,* **21**, 297-330.

Noakes, T.D. and Durandt, J.J. (2000). Physiological requirements of cricket, *Journal of Sport Sciences,* 18, **12**, 919-929.

Portus, M.R., Sinclair, P.J., Burke, S.T., Moore, D.J.A. and Farhart, P.J. (2000). Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sport Sciences.* 18, **12**, 999-1011.

Reilly, T., Secher, N., Snell, P. and Williams. (1990). *Physiology of Sports* , E & FN SPON, London.

Spencer, M., Bishop, D., Dawson, B., Goodman, C. and Duffield, R. (2006). Metabolism and performance in repeated cycle sprints: active versus passive recovery. *Medicine & Science in Sports & Exercise*. 38, **8**, 1492-1499.

Swain, D. P., Abernathy, K. S., Smith, C. S., Lee, S. J. and Bunn, S. A. (1993). Target heart rates for the development cardiorespiratory fitness. *Medicine and Science in Sports and Exercise.* 26, **1**, 112-116.

Tomlin, D.L. and Wenger, H.A. The Relationship Between Aerobic Fitness and Recovery from High Intensity Intermittent Exercise. *Sports Medicine,* 2001, 3, **1**, 1-11.

Vincent, W. J. (1999). *Statistics in Kinesiology (second edition).* Human Kinetics, Leeds.

Wilmore, J.H. and Costill, D.L. (1994). *Physiology of Sport and Exercise Science.* Human Kinetics, Leeds.

APPENDICIES

APPENDIX A

INFORMED CONSENT

PARTICIPANT CONSENT FORM

Outline

For this study the subject will be required to complete a ten over spell of bowling whilst having their heart rate and bowling speeds recorded.

Details

The participant will have a heart rate transmitter belt fixed around their chest (with an electrolyte gel on the transmitters), and a watch on their front bowling arm wrist to monitor the heart rate. The signal shall be tested for quality. The subject will complete an eight-minute warm up. This should consist of a four-minute progressive run and three minutes of stretching, with an extra minute for participants to complete their own stretches. The subject will then have an opportunity for three practice deliveries prior to the study.

Once the warm up is complete the heart rate monitor shall begin recording the ten over bowling spell. The subject will deliver six legitimate balls, ensuring that the front foot is not overstepping the front line. Once the over is complete the bowler will have a three-minute recovery period. Once the recovery period is finished the bowler will complete the next over until the bowling spell is complete.

Recovery Periods

Passive Recovery

During the recovery periods the bowler will have a passive recovery period. This is to stimulate the cricket environment, as the bowlers will rarely field the ball during a spell. The average fielder will have to field the ball 8.1 balls per hour. In order to replicate this the bowler will have to field 8 balls rolled out to them and throw them back into a wicketkeeper, to simulate the cricket environment. The administrator will randomly assign the fielding drills. The bowler must simulate the recovery period as much as possible so there will be limited talking, no lavatory breaks and fluid replenishment will be allowed at the end of the over. The resting bowler must also “walk in” with the bowler who is currently in there over.

Active recovery

During the active recovery intermittent exercise is required to maintain heart rate and work at a calculated percentage of $VO2_{max}$ (55%). A predicted value will be assigned to the subject prior to the test. It is the subject’s responsibility to complete intermittent exercise such as shuttle runs or dynamic stretching to maintain the prescribed heart rate. The heart rate will also be monitored by the administrator to ensure validity. During this protocol eight fielding drills will be randomly distributed per hour, there will be limited talking, no lavatory breaks and fluid replenishment will be allowed at the end of the over.

Validity

To ensure the validity of the test and the quality of results the mean velocity of the first six deliveries shall be calculated. The bowler must then keep their speed within 10% of that value to ensure that the subject is performing with maximum effort throughout the study.

Physical Active Readiness Questionnaire

Circle appropriate answer

1. Has your doctor ever said that you have a heart condition or can only do exercise as prescribed by your doctor? Y/N

2. Do you have any great discomfort when partaking in exercise? Y/N

3. Do you have a bone or joint problem that can be made worse by taking part in physical activity? Y/N

4. Is your doctor currently prescribing you drugs or medication for blood pressure or heart condition? Y/N

5. Do you loose your balance because of dizziness or do you ever loose consciousness? Y/N

6. Do you feel pain in your chest when partaking in exercise? Y/N

7. In the past month had you had chest pain when not partaking in physical activity?

Participant Consent Form

Please **initial** each statement

- I have read and understood the procedure of the study fully and have had an opportunity to ask questions and consider the study.

- I understand that the study will be physically demanding and I have the opportunity to leave the study at any point without giving reason

- I give consent to take part in this study

Name (CAPITALS)…………………………….

D.O.B…………………………….

Recovery format (delete as necessary) Passive / Active

Signature …………………………

Date………………………………

APPENDIX B

PILOT STUDY

Bowling speed using passive recovery (km/h^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**
1	115.9	120.2	117	114.1	116	112.8	116.6	116
2	117.1	117	114.2	116.4	115.5	111.5	114.5	114.7
3	118.6	116.3	117.6	111.2	116.6	113.2	115	112.8
4	117.6	115.8	118.6	115.3	116.3	113.2	112.4	117.2
5	118.3	115.3	114.2	116.5	115.5	112.4	113.5	111.6
6	118.5	117.1	116.6	112.9	109.8	110.4	116.3	110.6

Heart rate data grouped into 10-minute averages

Time (mins)	Pilot Study (bpm^{-1})
0-10	142.1
10-20	160.7
20-30	158.3
30-40	163.7
40-50	163.4
50-60	173.7

APPENDIX C

HEART RATE DATA

SUBJECT 1. Heart rate data grouped into 10-minute averages

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	142.2	154.8
10-20	158.1	161.2
20-30	159.4	167.2
30-40	155.2	163.8
40-50	145.1	167.9
50-60	154.4	165.7
60-end	154.8	163.7

SUBJECT 2. Heart rate data grouped into 10-minute average

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	156.6	156.5
10-20	159.6	156.4
20-30	161	158.7
30-40	166.4	161
40-50	150	151.6
50-60	161.2	154.2
60-end	154	158.1

SUBJECT 3. Heart rate data grouped into 10-minute average

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	130	116.1
10-20	124.7	126
20-30	140.2	128.7
30-40	142.6	129.5
40-50	144.5	124
50-60	143.7	134
60-end	137.8	139.1

SUBJECT 4. Heart rate data grouped into 10-minute average

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	124.7	132.8
10-20	120.7	136.2
20-30	128.8	149.3
30-40	131.1	149.4
40-50	132.6	144.3
50-60	134.2	153.7
60-end	129	149.4

SUBJECT 5. Heart rate data grouped into 10-minute average

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	160.7	162.8
10-20	158.8	163.3
20-30	171.9	174.7
30-40	167.5	170.3
40-50	173.6	172.8
50-60	165.6	159.8
60-end	183.2	179.2

SUBJECT 6. Heart rate data grouped into 10-minute average

Time (mins)	Passive recovery (bpm^{-1})	Active recovery (bpm^{-1})
0-10	143.8	139.8
10-20	135.8	136.8
20-30	150.7	141
30-40	139.7	139.4
40-50	148.1	140.3
50-60	140.6	145.7
60-end	163	N/A

APPENDIX C

BOWLING SPEED

SUBJECT 1

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	64.5	66.5	66.6	65.3	64.4	64.5	65.7	63	61.9	61.4
2	62.9	65.4	67.4	66.1	66.6	64.5	62.6	60	61.4	63.3
3	63.5	66.9	68	63.1	64.6	60.5	64.2	61.6	63.8	60.3
4	65.1	65.9	67.7	66	65.3	63	63.9	61.9	61.3	60.9
5	66.1	64.8	**68.3**	62.4	66	62.8	62.6	61.3	61.3	61.1
6	65.3	66.9	65.6	67.2	63.4	61.7	62	65.4	61.8	64

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	58.3	62.8	60.3	62.9	62.6	60.6	60.4	58.6	58.4	60.2
2	60.6	64.3	61.8	62.5	60.3	60.8	62.6	60.5	57.9	60.6
3	62.6	64.7	62.6	62.6	63.8	60.8	61.5	59.3	59.8	58.2
4	61	62.9	64.4	59.9	61.7	59	63.5	58.7	59.6	57.2
5	64.1	62.4	60.1	64	61.5	63.6	62.4	61.8	60.1	59
6	**64.8**	63.5	63.3	62.5	62.7	61.5	64.4	60.7	60.3	58.4

SUBJECT 2

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	68.2	**71**	67.6	67.7	67.3	69.1	66.8	68.5	66.2	65
2	69	68.1	67	67.1	67.7	68	68.7	67.9	66.9	65.1
3	69	67.6	65	66.9	67.2	68.1	66.9	67.1	66.9	66.1
4	68.6	67.8	67.6	66.6	66.8	68.5	69.4	66.7	65.3	66.3
5	67.6	68.3	67.3	67.1	67.5	68.1	67.8	67.2	67.2	65.3
6	68.7	67	67.2	67.1	63.4	67.2	64.6	67.2	67.7	66.8

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over 1**	**Over 2**	**Over3**	**Over 4**	**Over 5**	**Over 6**	**Over 7**	**Over 8**	**Over 9**	**Over 10**
1	65.5	66.4	65.3	64.9	66.8	67.1	69.1	65.7	68.5	67.1
2	64.4	67	67.7	69.6	69.3	68	65	70.8	69.8	68.4
3	66.4	68.2	68.4	70.3	67.6	69.9	66.6	65.2	66	68.2
4	66.7	67.3	66.5	70.6	66.3	67.9	68.3	67.8	66.4	68.7
5	66.5	68.4	66.5	70.4	66.9	68.5	66.2	69.8	69.3	69.2
6	67.7	66.9	67.5	68.4	70.1	67.2	**71.4**	66.2	65.5	65.6

SUBJECT 3

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	68.2	69.9	69.1	69.5	**72.5**	69.7	69.9	72.1	69.8	66.9
2	68.3	69.9	70.1	71.7	71.1	67.5	69	68.3	69.8	70.3
3	66.4	68.6	71.1	68.8	71.1	70.7	72.3	66.8	69	68.8
4	69	68.7	70.7	68.8	69.9	71.5	67.8	70.2	69.8	64.7
5	68	67.8	67.8	70.6	68.1	69.5	68.2	69.8	70.6	64.6
6	69.4	68.1	69	70	70.4	71.4	70.6	69.1	68.6	66.8

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over 1**	**Over 2**	**Over3**	**Over 4**	**Over 5**	**Over 6**	**Over 7**	**Over 8**	**Over 9**	**Over 10**
1	64.6	65	69.4	69.2	69.7	68.3	67.3	66.2	66.2	67.5
2	66.4	65.9	69.4	69.1	68	70	65.9	67.8	68.9	65.8
3	64.8	65.5	67	68.4	68.7	67.6	65.7	65.3	67.9	69
4	64.1	67.2	66.8	**70.3**	66.9	66	67.9	67.1	66.1	66.8
5	65	64.9	68.3	68.4	69.4	69	64.9	64.7	66.6	68
6	65.5	65	68.3	69.7	68.4	69	68.5	64.3	68	66.6

SUBJECT 4

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	59.4	57.7	57.3	56.7	59.5	60.3	60.9	56	55.9	54.7
2	60.3	58.5	58.2	60.1	59.4	59.6	59.6	58.3	59.4	56.9
3	60.3	58.5	58.8	61	59.4	59.3	59	56.8	57.9	52.7
4	59.2	58.5	59.2	60.5	57.7	59.5	57.9	59.4	57.8	58.3
5	60.4	58.3	59.2	58	58.5	57.7	59.3	60	57.9	57.5
6	57.5	58.6	57.4	58.5	59.2	59.5	56.9	**61.2**	56.5	56.4

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over 1**	**Over 2**	**Over3**	**Over 4**	**Over 5**	**Over 6**	**Over 7**	**Over 8**	**Over 9**	**Over 10**
1	56.1	55.1	55.2	**60.9**	59.6	58	58.1	55.9	60.1	57.3
2	56.5	56.3	58.3	60.1	59.1	59.2	58.1	57.5	60.1	55.2
3	56.7	56.3	**58.3**	59.7	**59.9**	60.4	57.4	57.5	60.3	56.6
4	**59.1**	54.7	57.9	59	59	58.3	57.4	58.1	58.8	55.6
5	56.7	**58.2**	56.6	58.9	57.8	58.1	58.6	58.3	54.4	57.2
6	57.5	57.6	56.1	58.1	59.5	57.8	57	57.1	58.4	58.6

SUBJECT 5

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	70	70.3	68.7	59.1	**72.2**	70.8	69.8	68.9	70.5	65.1
2	70.4	70.5	70.1	67.6	70.2	60.5	68.3	67.2	70.6	69.9
3	71.7	70.8	69.7	67.4	70.6	67.6	68.5	68.7	69.3	69.7
4	69	70.3	68.6	68	70.9	60.4	69.5	68.9	69.3	68.7
5	59.2	71.5	69.2	69	59	61.3	58.1	69.8	68.8	65.1
6	69.1	68.9	67.9	70.8	67.6	70.6	68.6	68.7	70.5	70.1

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over 1**	**Over 2**	**Over3**	**Over 4**	**Over 5**	**Over 6**	**Over 7**	**Over 8**	**Over 9**	**Over 10**
1	68.3	69.8	66.3	68.1	68.5	68.3	69.7	67.8	66.8	67.7
2	67.3	65.5	68.8	66.5	65.9	70.5	66.8	69.9	65.5	66.7
3	68.5	67.7	65	68.9	67.8	67.1	67.3	67.7	64.7	67.2
4	66.6	68.2	66.2	69.2	69.3	69.2	66.8	68.1	65.7	67.2
5	66.6	68.5	65.6	69.4	**72.4**	69.2	66.8	65.7	65	68
6	68.2	68.8	67.6	68.4	70.1	66.4	68.7	69.5	66	68.1

SUBJECT 6

Passive Recovery. Bowling speed (mph^{-1})

Delivery Number	**Over1**	**Over2**	**Over3**	**Over4**	**Over5**	**Over6**	**Over7**	**Over8**	**Over9**	**Over10**
1	59.4	57.6	57.2	57	58.3	58.5	58.3	56.9	57.7	54.4
2	58.8	59.6	58.4	56.7	59.2	58.7	57.5	55.9	56.6	54.4
3	58.1	59.2	59.6	57.7	58.1	58	57.9	56.1	59	56
4	57.8	56.8	58.4	58.3	57.6	58.3	58.2	56.7	58.3	56.2
5	58.1	58.8	**60.1**	58.4	58.4	57.7	57.7	57.2	57.2	55.2
6	58	59.7	58.1	58.4	57.2	58.5	57.8	55.9	57.9	56.4

Active Recovery. Bowling speed (mph^{-1})

Delivery number	**Over 1**	**Over 2**	**Over3**	**Over 4**	**Over 5**	**Over 6**	**Over 7**	**Over 8**	**Over 9**	**Over 10**
1	57.6	58.3	58	57	57.3	57.1	58	58.1	58.2	58
2	58.3	56.8	57.4	57.5	57.2	58.9	59.9	57.7	58.2	58.7
3	58	**60.3**	56.8	56.7	58.3	56.7	58.3	58.5	59.2	59
4	57.9	56.5	57.5	58	57	59.5	57.2	58	58.8	58.4
5	57	57	56.3	58.7	57.6	56.5	58	58.1	60.2	59
6	56.9	58.4	58	56.5	59.2	59.6	59.7	60	59.6	59.1

APPENDIX D

SPSS OUTPUT

Fatigue Index Data

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Passive	12.7750	6	3.63159	1.48259
	Active	9.7150	6	1.79741	.73379

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Passive & Active	6	.543	.266

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Passive - Active	3.06000	3.05464	1.24705	-.14565	6.26565	2.454	5	.058

Paired T Test Active vs. Passive bowling Speeds

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Passive1	64.5694	36	4.66781	.77797
	Passive2	65.0917	36	4.99184	.83197
Pair 2	Passive1	64.5694	36	4.66781	.77797
	Passive3	64.9778	36	4.83559	.80593
Pair 3	Passive1	64.5694	36	4.66781	.77797
	Passive4	64.3111	36	4.84637	.80773
Pair 4	Passive1	64.5694	36	4.66781	.77797
	Passive5	64.6194	36	5.12611	.85435
Pair 5	Passive1	64.5694	36	4.66781	.77797
	Passive6	63.9750	36	4.85453	.80909
Pair 6	Passive1	64.5694	36	4.66781	.77797
	Passive7	64.0778	36	4.90854	.81809
Pair 7	Passive1	64.5694	36	4.66781	.77797
	Passive8	63.7972	36	5.26658	.87776
Pair 8	Passive1	64.5694	36	4.66781	.77797
	Passive9	63.9000	36	5.25558	.87593
Pair 9	Passive1	64.5694	36	4.66781	.77797
	Passive10	62.3722	36	5.38599	.89767
Pair 10	Active1	62.5778	36	4.29825	.71637
	Active2	63.1194	36	4.69686	.78281
Pair 11	Active1	62.5778	36	4.29825	.71637
	Active3	63.0417	36	4.75198	.79200
Pair 12	Active1	62.5778	36	4.29825	.71637
	Active4	64.3139	36	5.00646	.83441
Pair 13	Active1	62.5778	36	4.29825	.71637
	Active5	64.0611	36	4.81292	.80215
Pair 14	Active1	62.5778	36	4.29825	.71637
	Active6	63.7667	36	4.83960	.80660
Pair 15	Active1	62.5778	36	4.29825	.71637
	Active7	63.4833	36	4.43998	.74000
Pair 16	Active1	62.5778	36	4.29825	.71637

	Active8	62.8889	36	4.68126	.78021
Pair 17	Active1	62.5778	36	4.29825	.71637
	Active9	62.9250	36	4.21693	.70282
Pair 18	Active1	62.5778	36	4.29825	.71637
	Active10	62.8361	36	4.92702	.82117
Pair 19	Passive1	64.5694	36	4.66781	.77797
	Active1	62.5778	36	4.29825	.71637
Pair 20	Passive2	65.0917	36	4.99184	.83197
	Active2	63.1194	36	4.69686	.78281
Pair 21	Passive3	64.9778	36	4.83559	.80593
	Active3	63.0417	36	4.75198	.79200
Pair 22	Passive4	64.3111	36	4.84637	.80773
	Active4	64.3139	36	5.00646	.83441
Pair 23	Passive5	64.6194	36	5.12611	.85435
	Active5	64.0611	36	4.81292	.80215
Pair 24	Passive6	63.9750	36	4.85453	.80909
	Active6	63.7667	36	4.83960	.80660
Pair 25	Passive7	64.0778	36	4.90854	.81809
	Active7	63.4833	36	4.43998	.74000
Pair 26	Passive8	63.7972	36	5.26658	.87776
	Active8	62.8889	36	4.68126	.78021
Pair 27	Passive9	63.9000	36	5.25558	.87593
	Active9	62.9250	36	4.21693	.70282
Pair 28	Passive10	62.3722	36	5.38599	.89767
	Active10	62.8361	36	4.92702	.82117

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Passive1 & Passive2	36	.866	.000
Pair 2	Passive1 & Passive3	36	.852	.000
Pair 3	Passive1 & Passive4	36	.786	.000
Pair 4	Passive1 & Passive5	36	.927	.000
Pair 5	Passive1 & Passive6	36	.826	.000
Pair 6	Passive1 & Passive7	36	.932	.000
Pair 7	Passive1 & Passive8	36	.858	.000
Pair 8	Passive1 & Passive9	36	.876	.000
Pair 9	Passive1 & Passive10	36	.888	.000
Pair 10	Active1 & Active2	36	.926	.000
Pair 11	Active1 & Active3	36	.907	.000
Pair 12	Active1 & Active4	36	.894	.000
Pair 13	Active1 & Active5	36	.900	.000
Pair 14	Active1 & Active6	36	.910	.000
Pair 15	Active1 & Active7	36	.940	.000
Pair 16	Active1 & Active8	36	.907	.000
Pair 17	Active1 & Active9	36	.821	.000
Pair 18	Active1 & Active10	36	.864	.000
Pair 19	Passive1 & Active1	36	.880	.000
Pair 20	Passive2 & Active2	36	.945	.000
Pair 21	Passive3 & Active3	36	.883	.000
Pair 22	Passive4 & Active4	36	.842	.000
Pair 23	Passive5 & Active5	36	.774	.000
Pair 24	Passive6 & Active6	36	.764	.000
Pair 25	Passive7 & Active7	36	.819	.000
Pair 26	Passive8 & Active8	36	.872	.000
Pair 27	Passive9 & Active9	36	.865	.000
Pair 28	Passive10 & Active10	36	.856	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Passive1 - Passive2	-.52222	2.52135	.42023	-1.37532	.33088	-1.243	35	.2
Pair 2	Passive1 - Passive3	-.40833	2.59146	.43191	-1.28516	.46849	-.945	35	.3
Pair 3	Passive1 - Passive4	.25833	3.11754	.51959	-.79649	1.31316	.497	35	.6
Pair 4	Passive1 - Passive5	-.05000	1.92954	.32159	-.70286	.60286	-.155	35	.8
Pair 5	Passive1 - Passive6	.59444	2.81506	.46918	-.35803	1.54692	1.267	35	.2
Pair 6	Passive1 - Passive7	.49167	1.77561	.29593	-.10911	1.09245	1.661	35	.1
Pair 7	Passive1 - Passive8	.77222	2.70941	.45157	-.14451	1.68896	1.710	35	.0
Pair 8	Passive1 - Passive9	.66944	2.53589	.42265	-.18858	1.52747	1.584	35	.1
Pair 9	Passive1 - Passive10	2.19722	2.47934	.41322	1.35833	3.03611	5.317	35	.0
Pair 10	Active1 - Active2	-.54167	1.77190	.29532	-1.14119	.05786	-1.834	35	.0
Pair 11	Active1 - Active3	-.46389	1.99802	.33300	-1.13992	.21214	-1.393	35	.1
Pair 12	Active1 - Active4	-1.73611	2.24743	.37457	-2.49653	-.97569	-4.635	35	.0
Pair 13	Active1 - Active5	-1.48333	2.10054	.35009	-2.19406	-.77261	-4.237	35	.0
Pair 14	Active1 - Active6	-1.18889	2.00909	.33485	-1.86867	-.50911	-3.551	35	.0
Pair 15	Active1 - Active7	-.90556	1.51958	.25326	-1.41971	-.39141	-3.576	35	.0
Pair 16	Active1 - Active8	-.31111	1.97466	.32911	-.97924	.35702	-.945	35	.3
Pair 17	Active1 - Active9	-.34722	2.55080	.42513	-1.21029	.51584	-.817	35	.4
Pair 18	Active1 - Active10	-.25833	2.48071	.41345	-1.09769	.58102	-.625	35	.5

Pair 19	Passive1 - Active1	1.99167	2.22433	.37072	1.23906	2.74427	5.372	35	.0
Pair 20	Passive2 - Active2	1.97222	1.63578	.27263	1.41875	2.52569	7.234	35	.0
Pair 21	Passive3 - Active3	1.93611	2.32504	.38751	1.14943	2.72279	4.996	35	.0
Pair 22	Passive4 - Active4	-.00278	2.77257	.46209	-.94088	.93532	-.006	35	.9
Pair 23	Passive5 - Active5	.55833	3.35290	.55882	-.57612	1.69279	.999	35	.3
Pair 24	Passive6 - Active6	.20833	3.33324	.55554	-.91947	1.33614	.375	35	.7
Pair 25	Passive7 - Active7	.59444	2.84725	.47454	-.36893	1.55781	1.253	35	.2
Pair 26	Passive8 - Active8	.90833	2.57708	.42951	.03637	1.78029	2.115	35	.0
Pair 27	Passive9 - Active9	.97500	2.65711	.44285	.07596	1.87404	2.202	35	.0
Pair 28	Passive10 - Active10	-.46389	2.80633	.46772	-1.41342	.48564	-.992	35	.3

ANOVA with Friedman's Test and Tukey's Test for Nonadditivity

	Sum of Squares	df	Mean Square	Friedman's Chi-Square	Sig
Between People	7710.851	35	220.310		

Within People	Between Items		193.458	9	21.495	6.128	.000
	[illegible]	Nonadditivity	7.836[a]	1	7.836	2.243	.135
		Balance	1097.163	314	3.494		
		Total	1104.999	315	3.508		
	Total		1298.457	324	4.008		
Total			9009.308	359	25.096		

Grand Mean = 64.1692

a. Tukey's estimate of power to which observations must be raised to achieve additivity = 3.791.

Intraclass Correlation Coefficient

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.844	.773	.904	54.973	35	324	.000
Average Measures	.982	.971	.990	54.973	35	324	.000

One-way random effects model where people effects are random.